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Barite and Fluorspar in Ontario: Resources and Options for Production

By:
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Cover photo inset:

Specimens of banded white barite from Hemlo and green fluorspar from Madoc, Ontario; barite and fluorspar are valued industrial minerals in chemical manufacturing.



Note: This paper does not represent official policy and the views expressed herein are not necessarily the viewpoint of the Government of Ontario. The authors represent that they have followed standard procedures in preparing the evaluation in the Report, but the Report is based in part on details, information and assumptions provided by others and the authors, therefore, cannot guarantee the correctness of the Report; but to the extent of its investigation and within, the scope of the work delegated to it, the authors believe that the Report is substantially correct.

Table of Contents

Summary	5
1. General Introduction	9
Terms of Reference	9
Methodology	9
2. Barite and Fluorspar Resources In Ontario	11
Introduction	11
Mineral Descriptions	11
Previous Studies	13
History of Production	14
Occurrences in Northwestern Ontario	15
Occurrences in Northeastern Ontario	22
Occurrences in Southeastern Ontario	25
Commentary	29
3. Options for Barite Mineral Production	31
Existing Production	31
Production Options	31
Production Costs	35
4. Options for Barium Chemicals Production	41
Production Options	41
Production Costs	57
5. Options for Fluorspar Production	61
Production Options	61
Specifications	62
Production Costs	64
6. Implications for Small Mines	65
Custom Milling	65
By-Product Recovery	66
7. Conclusions and Recommendations	69
Conclusions	69
Recommendations	70
Selected Bibliography	71
Resources	71
Options for Production	73
Appendices	75
A. Barite Mill Processing Equipment	75
Major Items and Typical Costs	76
B. Barium Chemicals Plant Equipment	77
Major Items and Typical Costs	78
C. Fluorspar Mill Processing Equipment	81
Major Items and Typical Costs	81

Summary

The prime objective of the study was to evaluate the technical and economic potential of barium chemicals and high quality fluorspar (fluorite) in Ontario based on small mining operations, by-product mineral recovery, custom mineral processing and established/emerging chemicals production technologies.

There are numerous recorded occurrences of barite and/or fluorspar throughout Ontario. Up to 1961, the province was a producer of fluorspar from shallow workings in vein deposits in Southeastern Ontario; barite has been extracted from several veins, principally in Northern Ontario, for periods dating back to the last century. Further exploration of these occurrences, to investigate the possibilities of economic reserves, have rarely been carried out. The present-day viability of working small deposits for specialty markets has been successfully demonstrated by the province's current producer of barite in Northeastern Ontario.

Metals exploration programs in recent years have led to the incidental discovery of significant deposits of these industrial minerals in terms of volume, for example, that of stratiform barite in the Hemlo gold belt, and of fluorspar in the Springpole Lake alkaline igneous complex, both in Northern Ontario. Such discoveries encourage the view that concentrations of potential interest remain to be identified by explorationists in the province.

Barite

A review of barite mineral resources in the province of Ontario revealed that mineral deposits of Northern Ontario in the Thunder Bay area and the Matachewan area or by-product barite contained in gold mill tailings from Hemlo area mining operations could potentially support the production of 15,000 to 30,000 tonnes per year of high grade barite (94% BaSO_4 , minimum). A central processing mill treating ore from one or more mining locations would be required in order to produce 30,000 tonnes per year of barite in either mineral deposit area (Thunder Bay or Matachewan), whereas, a single processing mill could produce the required tonnage of barite from a portion of the Hemlo area gold mill tailings.

Capital requirements and total production costs for the production of barite depend on the location of the processing mill or mills, the quantity of barite being produced and the grade of the barite ore/gold mill tailings material and are shown in Table 1.

The total production costs include all direct operating costs, capital recovery charges and product shipping charges to a barium chemicals plant in the Thunder Bay area (for the Thunder Bay and Hemlo mill locations) or in a central Ontario location closer

Table 1

Capital Requirements and Productions Costs for Various Mill Locations

Mill Location	Mill Capacity, t/a	Capital Cost \$	Total Production Cost, \$/t Barite
Thunder Bay	30,000	3,000,000	108
	15,000	3,000,000	151
Matachewan	30,000	3,000,000	213
	15,000	3,000,000	274
Hemlo	30,000	8,400,000	180

to the barium chemicals markets (for the Matachewan and twin mill locations).

The indicated price of \$108 per tonne for 30,000 tonnes per year of barite from a single Thunder Bay mill is considered to be optimistic as established barite reserves in the area may not be sufficient to support the 30,000 tonnes per year operation. A more realistic price to consider for 30,000 tonnes per year of barite is \$180 to \$210 per tonne, based either on the recovery of barite from Hemlo area gold mill tailings or on its production in twin 15,000 tonnes per year mills in the Thunder Bay and Matachewan areas, with barite being shipped to a centrally located chemicals plant. All costs developed in this study must be considered preliminary as they are based on a minimum level of information concerning mineral deposits, metallurgical testing and processing options.

Employment opportunities would be created with the introduction of a new barite mining and milling operation in Ontario. The number of jobs created depends on the barite mill location, the mill capacity and the type of operation and are shown in Table 2.

Additional job opportunities would be created in

the Thunder Bay and Matachewan cases for contract mining of the barite ore.

Barium Chemicals

An investigation of potential market opportunities for barium chemicals resulted in an evaluation of the technical and economic potential of producing barium sulphide (BaS), barium carbonate (BaCO₃), barium chloride (BaCl₂), barium sulphate (BaSO₄), barium oxide (BaO) and barium hydroxide (Ba(OH)₂) in an integrated chemicals complex capable of processing 30,000 tonnes per year of barite:

- BaS — 20,000 tonnes per year, primarily for captive use but with up to 4,400 tonnes per year available for sale
- BaCO₃ — 16,000 tonnes per year capacity, with normal production rates of 12,000 tonnes per year for sale and 1,950 tonnes per year for captive use (BaO production)
- BaCl₂ — 5,000 tonnes per year capacity, with a normal operating rate of 3,500 tonnes per year
- BaSO₄ — 1,500 tonnes per year capacity, with a normal production rate of 1,000 tonnes per year.

Table 2

Job Creation for Various Mill Locations

Mill Location	Mill Capacity, t/a	Estimated Job Creation
Thunder Bay	30,000	14
	15,000	11
Matachewan	30,000	15
	15,000	12
Hemlo	30,000	17

Table 3
Capital and Production Costs for Various Barium Chemicals

Chemical	Capital Cost, \$ million	Plant Gate Production Cost, \$/tonne	
		Barite @ \$108/t	Barite @ \$180-210/t
BaS	11	413	520-565
BaCO ₃	7	592	685-725
BaCl ₂	4.8	1098	1185-1220
BaSO ₄	1.6	1085	1165-1200
BaO	4.6	1890	2010-2060
Ba(OH) ₂			
Monohydrate	—	1535	1635-1675
Octahydrate	—	920	980-1000
Capital Cost	29		
Total Facility			

- BaO and Ba(OH)₂ — 3,000 tonnes per year BaO capacity, with a normal operating rate of 1,500 tonnes per year BaO equivalent, as barium oxide and hydroxides.

The precursor of most barium chemicals is BaS including, BaCO₃, BaCl₂, and BaSO₄. Barium carbonate is used as the raw material in the production of BaO/Ba(OH)₂.

Capital costs and plant gate production costs for the barium chemicals depend on the chemical being produced, the cost of raw materials and the plant capacity illustrated in Table 3.

Sodium sulphide (Na₂S) is produced as a by-product during the production of BaCO₃, BaCl₂ and BaSO₄. It is recovered for sale to the pulp and paper industry as a substitute for Na₂SO₄ in Kraft pulp mills. Based on an analysis of reported market prices for barium chemicals (Law, Sigurdson and Associates, SRI International 1989), it appears that the production of barium

sulphide, barium carbonate and, possibly, barium sulphate offers reasonable technical and economic potential provided that low-cost barite can be delivered to the barium chemicals plant and that their reported market prices are realistic for large quantity sales (Table 4).

The above cost for BaSO₄ is based on its production in a multi-product plant capable of producing BaCO₃ and BaSO₄ in blocked operation. Earlier costs, \$1,085 to \$1,200 per tonne, were based on production in a dedicated process unit.

The production of BaCl₂, BaO and Ba(OH)₂ does not appear to have any significant economic potential as indicated production costs (Table 5) are well in excess of reported market values.

Employment opportunities would be created with the production of barium chemicals in Ontario. An estimated operations, maintenance and administration staff of 38 personnel would be required for a barium

Table 4
Production Costs and Market Value for some Barium Chemicals

Chemical	Estimated Production Cost, \$/tonne	Reported Market Value, \$/tonne
BaS	413-565	N/A
BaCl ₂	592-725	550-800
BaSO ₄	815-930	800

Table 5
Production Cost and Market Value for Barium Chemicals

Chemical	Estimated Production Cost, \$/tonne	Reported Market Value, \$/tonne
BaCl ₂	1098-1220	500-840
BaO	1890-2060	N/A
Ba(OH) ₂		
Monohydrate	1535-1675	1100-1200
Octahydrate	920-1000	N/A

chemicals plant capable of producing BaS, BaCO₃ and BaSO₄. Additional staff would be required to market the barium chemicals in Canada and the Eastern United States.

Fluorspar

A review of fluorspar reserves in the Madoc area of South-Eastern Ontario indicated that local mineral deposits could possibly support the production of 15,000 tonnes per year of acid grade fluorspar (97% CaF₂, minimum) or 20,000 tonnes per year of metallurgical grade fluorspar (70% CaF₂).

Capital requirements and total production costs for the production of fluorspar depend on the mill location, the ore grade and the quantity and grade of fluorspar being produced (See Table 6).

Low shipping costs for these materials to Ontario-based consumers should overcome the probable lower production costs of major suppliers of imported material, making the Ontario-produced product economically attractive. Total imports into Canada amounted to 194,000 tonnes of all grades in 1988, thus the identified market potential.

Employment opportunities would be created with the introduction of a fluorspar mining and milling operation in Ontario. An estimated staff of 14 personnel would be required for the fluorspar milling operation, plus additional contract mining jobs.

Recommendations

Before serious consideration can be given to the development of barite and fluorspar reserves in Ontario and the production of barium chemicals (to take advantage of potential market opportunities in Canada and the Eastern United States) additional work should be undertaken to establish the reliability of the most attractive options.

1. Base level proven and probable reserves should be established.
2. Representative ore samples should be tested to develop cost effective metallurgical processing routes. Potential mine and processing mill locations should be examined and feasibility studies should be conducted to assess selected mineral processing options and costs.
3. Market opportunities for barium chemicals should be clearly defined, potential chemical plant locations should be examined and a detailed feasibility study should be completed to assess selected barium chemicals production options and costs.

Table 6
Capital requirements and production costs for acid and metallurgical grade fluorspar

Fluorspar Grade	Mill Capacity, t/a	Capital Cost, \$	Total Production Cost, \$/tonne
Acid	15,000	3,800,000	198
Metallurgical	20,000	2,000,000	90

1. General Introduction

This study was commissioned by the Mineral Development and Lands Branch of the Ontario Ministry of Northern Development and Mines as an extension of a study previously completed for the Ministry by Law, Sigurdson and Associates and SRI International (1989). The earlier study identified chemical derivatives of barite and fluorspar as two of the potential commercial opportunities in Ontario on the basis of market opportunity, mineral resource potential and existing industrial service infrastructure.

This document is based on a study report received in March 1990 from Kilborn Limited. The second chapter — Barite and Fluorspar Resources in Ontario — is a literature review by the Mineral Development Section of the Ministry of Northern Development and Mines and is an edited version of an internal report by D.M. Conrod of the Section.

Funding was provided by the Economic Development Program of the Canada-Ontario 1985 Mineral Development Agreement (COMDA). COMDA was a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the Governments of Ontario and Canada in 1984.

Terms of Reference

The principal objective of the study was to evaluate the technical and economic potential for the production of barium chemicals and high quality fluorspar in Ontario based on small mining operations, by-product mineral recovery, custom mineral processing and existing or emerging chemicals production technologies. Barite and fluorspar mineral supply options were to consider resource development in Northern and Eastern Ontario, by-product mineral recovery and mineral processing required to produce high quality barite (94% BaSO_4) and metallurgical grade or acid grade fluorspar (60% and 97% CaF_2 , respectively). Barium chemical production options were to include BaS , the precursor of most barium chemicals; a number of the high demand derivatives, BaCO_3 and BaCl_2 ; and additional secondary derivatives, BaSO_4 , BaO , barium peroxide (BaO_2), barium hydroxide (Ba(OH)_2), barium nitrate ($\text{Ba(NO}_3)_2$) etc.

Methodology

The initial activity in the study was the collection and review of available information on barite and fluorspar mineral resources in Ontario, mineral recovery techniques and barium chemical production methods and costs. The major activities in completing the study were:

1. Review of barite and fluorspar mineral resources in Ontario, by-product barite or fluorspar recovery possibilities.
2. Evaluation and selection of potential recovery methods for barite and fluorspar minerals, development of preliminary production costs.
3. Selection of barium chemicals to be studied.
4. Evaluation and selection of production methods for barium chemicals, development of preliminary production costs.

Barite and fluorspar mineral resources in Ontario were reviewed in order to determine the potential for commercial production at rates in the range of 30,000 tonnes per year barite (to support a commercial scale barium chemicals operation) and 10,000 to 15,000 tonnes per year of metallurgical grade or acid grade fluorspar. Consideration was given to the development of mineral resources, the recovery of by-product barite from gold mill tailings, the potential joint recovery of barite and fluorspar, the development of a number of small mineral deposits to meet the target production rates and the possible expansion of existing barite production facilities.

Based on the results of the resource review, processing steps required to recover high quality barite and acid grade or metallurgical grade fluorspar from open pit or underground mining operations and gold mill tailings were assessed and appropriate processing schemes were developed. This was followed by the development of preliminary capital cost and production cost estimates for each recovery option. In all cases that involved the processing of mineral reserves, the concept of an area processing plant being supplied with barite or fluorspar ore from several small mines in the vicinity of the plant was considered.

Production costs for the alternative processing schemes were compared and the processing routes showing the greatest economic potential were selected. High quality barite was considered as the raw material for the manufacture of a variety of barium chemicals, whereas, fluorspar (acid grade or metallurgical grade) was assessed on the basis of competitive sales in Ontario, other regions of Canada and the Eastern United States.

Potential opportunities for marketing barium chemicals in Canada and the Eastern United States were reviewed in order to select the barium chemicals included in the study, consisting of barium sulphide, the high demand derivatives barium carbonate and barium chloride, and additional secondary derivatives. This was followed by a review and selection of production alternatives for the barium chemicals, including established and emerging technologies and

processes that co-produced valuable by-product chemicals. The possibility of producing multiple chemicals in a single production facility in blocked operation was considered, particularly for the lower demand derivatives.

Simplified flow plans and overall material balances were developed for the production of commercial quantities of the selected barium chemicals, based on processing 30,000 tonnes per year of high quality barite (94% BaSO₄) from a Northern or Eastern Ontario ore processing plant. Preliminary capital cost and production cost estimates were developed for each barium chemical, taking into account appropriate credits for the sale of by-product chemicals. Blocked operation for the production of multiple chemicals in a single facility was evaluated, where practical, in order to lower the production costs of low demand secondary chemicals.

Production costs were compared to current market prices for the individual barium chemicals to determine their economic potential. Marketing of barium chemicals in Canada and the Eastern United States is considered to be a potential commercial opportunity as there is no Canadian production and only limited U.S. production.

In this study report, all costs are expressed in 1990 Canadian dollars. All tonnage values are metric tonnes unless otherwise noted. Additionally, fluorspar is used to describe the mineral fluorite as well as the metallurgical grade or acid grade product fluorspar.

2. Barite and Fluorspar Resources in Ontario

Introduction

Ontario, currently, has one small producer of barite. The province is a past producer of fluorspar; mining was discontinued in 1961.

The geological literature records over 300 occurrences of barite and/or fluorspar throughout the province, ranging from showings of interest only to the collector through to deposits of significant potential tonnage, such as those of the Hemlo area (barite) and the Red Lake area (fluorspar) in Northern Ontario. Most of the occurrences are narrow veins or fine disseminations within a variety of host rocks of various geological ages. While the majority of the veins are small and often discontinuous, many are of good in-situ grade.

Fluorspar and barite are often found together, with many of the occurrences in Ontario being concentrated in local areas; for example, 71 occurrences are located along two zones in the Thunder Bay area, 46 occurrences are reports in the Madoc-Moira Lake area and 28 occurrences are noted in the contiguous townships of Cardiff and Monmouth.

The only known stratiform barite deposit in Ontario is found in the gold ore zone of the Hemlo belt in Northern Ontario, and it also represents the largest barite occurrence in the province.

The summary of mineral resources in the following pages includes brief descriptions of selected principal occurrences. Map 1 is an index to the location maps for regions and districts of Ontario with occurrences of barite and fluorspar. Further details on specific occurrences in the province can be obtained from the references cited at the end of Part One and also by referring to the appropriate files in the offices of the Resident Geologists of the Ministry of Northern Development and Mines.

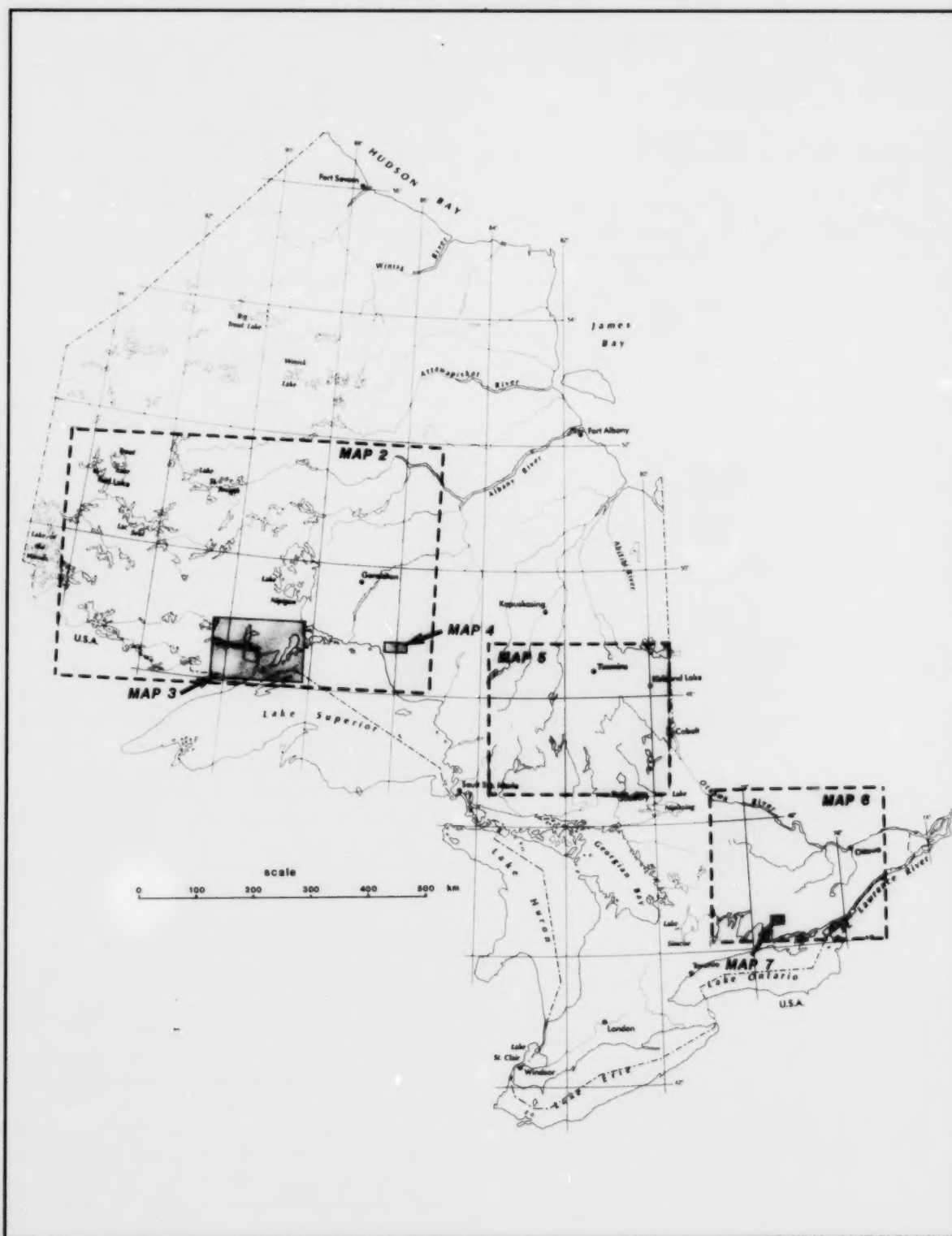
Mineral Descriptions

Fluorspar

Fluorspar (CaF_2), also known as fluorite, fluor, Blue John or Derbyshire spar, is the principal ore of fluorine. Fluorspar is used as a flux, in the manufacture of hydrofluoric acid, in the preparation of glass and enamels and for carved ornaments.

Fluorspar is a transparent to translucent mineral that crystallizes in either fine-grained aggregates or as coarse, individual crystals.

Pure fluorspar consists of 51.33% calcium and 48.66% fluorine by weight. Deer et al. (1980), state that most natural fluorspar is at least 99% CaF_2 , with



MAP 1. Index to Location Maps of Barite and Fluorspar Occurrences in Ontario.

minor amounts of silicon, aluminium and magnesium as impurities or inclusions within the fluorspar structure. Strontium, yttrium and the rare earth elements may replace a small portion of the calcium in fluorspar.

Fluorspar is a relatively soft mineral, having a hardness of four on the Mohs' scale. The refractive index of fluorspar varies between 1.433 and 1.435. The specific gravity of fluorspar ranges from 3.0 to 3.6 in massive finely crystalline varieties, while individual coarse crystals have a specific gravity of 3.2.

Fluorescence, a phenomenon which derives its name from fluorspar, is often strong and has been correlated to high contents of the rare-earths lanthanum, europium and cesium, (Deer et al. 1980). Yttrium and samarium may also play a role in the fluorescence of green fluorspar.

Natural fluorspar occurs in a wide range of colours. The presence of impurities within the crystal lattice, including the rare-earth elements (REEs), oxygen, hydrogen, water vapour, as well as the presence of colloidal particles, variations in the growth rate of the crystals, variations in pressure during and after crystal formation and exposure to light all contribute to the colour of fluorspar. (Naldrett et al. 1987) Although the intensity of coloration increases with an increase in the REE content, there is no apparent association between the presence of a particular REE and the colour of the fluorspar.

Barite

Barite (BaSO_4), also termed barytes, heavy spar or cawk, is the principal ore of barium. It is chiefly used in drilling muds and is an important ingredient in paint, paper and textile manufacture.

Barite is colourless or white and displays a vitreous to resinous lustre. The presence of impurities, including iron oxides and hydroxides, sulphides, and organic matter give barite a yellow, red or brown colour.

Pure barite contains 58.84 weight % barium. Most barite is pure BaSO_4 ; however, barium can be replaced by strontium in a continuous solid solution series from barite to celestite (SrSO_4). Lead and calcium can occasionally replace barium within the crystal structure (Deer et al. 1980). The high specific gravity of approximately 4.5 is a feature of the mineral; this increases or decreases with the substitution of lead or strontium respectively for barium.

Natural barite is usually found as well-formed tabular crystals in the orthorhombic system or as fine-grained aggregates occurring in globular, fibrous, lamellar or granular arrangements. Platy crystals, arranged in clusters, are often given the name of "desert rose."

The hardness of barite ranges between 2.5 and 3.5 on the Mohs' scale.

Previous Studies

A number of papers concerning Ontario fluorspar and its products were published between the early 1940's and early 1960's, corresponding to the relatively high production of fluorspar during that period. Guillet (1963) provided a detailed historical and geological compilation of barite occurrences in Ontario. The same author also published detailed historical and geological data for fluorspar in the Madoc-Moira Lake area (Guillet 1964).

A program of drilling, bulk sampling and beneficiation tests was carried out between 1941 and 1951 by the Geological Survey of Canada to evaluate the Madoc area's fluorspar resources at the former fluorspar-producing properties. Drilling results are summarized in Guillet (1964).

Detailed mineralogical and petrological studies of the Madoc ores were undertaken by Rupert (1963) and Mielke (1977). Rupert, through fluid inclusion analyses, determined that the ores were precipitated from several generations of solutions, ranging in temperature from 103° to 148°C. Mielke concluded that at least seven periods of fault activity and associated low temperature and low pressure hydrothermal mineralization can be recognized in the Rogers mine. Two sulphosalts, boulangerite and semseyite, were recognized with galena in the ore. Mielke concludes that these minerals grew from relatively cool dilute alkali-rich solutions.

Lalonde (1974) undertook a geochemical study of the secondary dispersion of fluorine in the Madoc-Moira Lake area, and concluded that most of the rocks within the area are enriched in fluorine. The fluorine content of groundwater was found to delineate areas of known fluorspar concentration.

A number of geophysical surveys were undertaken in the immediate Moira Lake area by Thompson and Williams between the years 1985 and 1990. These studies involved seismic, magnetic, resistivity, radioactivity and alpha meter surveys along six transects in an attempt to locate unknown faults and the extensions of known faults which may contain vein material. Thompson and Williams (1989) have recently combined their geophysical and structural studies of the area with the results of Lalonde's 1974 geochemical survey to locate potential ore targets. High concentrations of fluorine tend to fall along known or inferred faults in the area or at fault junctions.

A recent detailed mapping and geochemical soil

survey was undertaken in the Moira Lake area by Derry, Michener, Booth and Wahl in 1989 (Dickson and Trinder 1989). The survey resulted in the recognition of several coincident fluorite-barite-zinc target anomalies.

Summary compilations of fluorspar and barite occurrences in Ontario are provided by Vos et al. (1983) for Northern Ontario and Martin (1983) for the Algonquin Region.

Several studies of the barite located in the Hemlo area have been undertaken during the last six years. Roach (1987) carried out a petrological study of the Western Barite Occurrences located approximately 25 km west of Hemlo. He concluded that the occurrences were located in zones of heterogeneous ductile shear and that the barite-sulfide mineralization occurred before or during the ductile shearing event.

Gliddon (1985) undertook a petrological study of the barite at Hemlo, concluding that the deposit is most likely syngenetic in origin. Later studies of the deposit by Valliant and Bradbrook (1986) and Walford et al. (1986), however, suggest that the deposit may be epigenetic in origin. The question of origin is still to be settled.

Fluorspar and barite mineral collecting sites in Ontario are documented in a series of publications by Sabina (1963, 1969, 1971, 1976, 1983, 1986, 1987).

Petrological research and mapping to date of the Springpole Lake alkalic carbonatite complex and its associated fluorspar mineralization has been reported by Barron et al. (1989).

In addition to these studies, information concerning specific properties are available in the Ministry of Northern Development and Mines Assessment Files.

History of Production

Fluorspar

Between 1905 and 1961, 121,919 tons of fluorspar, mostly of metallurgical grade, were shipped from mines in the southeastern part of the province. Much of this production was achieved in response to wartime demand, as shown in Table 7.

The dominant fluorspar-producing area in Ontario has been in the Madoc area, where over 30 workings were recorded. Five properties, Rogers, Bailey, Noyes, Kilpatrick and Perry mines, accounted for 93% of Ontario's recorded shipments. The principal producer was the Rogers mine, which yielded a total of 45,000 tons, including 40,000 tons within a nine-year period.

Only 129 tons of fluorspar shipments were recorded from Cardiff Township from the Dwyer, Clarke and

Table 7
Fluorspar Production in Ontario
(Modified after Guillet 1964)

Period	Shipments (tons)
1905-1911	44
1916-1920	19,936
1921-1939	1,754
1940-1951	86,543
1952-1961	13,642

Tripp mines. There has been no fluorspar production in Ontario since 1961.

Mining in the Madoc area was carried out by small independent operators and only the pure, easily-sorted fluorspar was recovered. There was no mill for separation of the fluorspar in the banded calcite-barite-fluorspar portions of the veins. The mine-run ore was usually crushed and run over a picking belt where most of the lump fluorspar was recovered. This high-grade material was diluted with some of the calcite-fluorite-barite fines to ship 70% CaF_2 metallurgical grade. Mining was limited to shallow depths (110 m or less) because of heavy water flows, which the small mines did not have the equipment to control. When fluorspar production ceased in the Madoc area, an undetermined amount of ore remained at the bottom of the Rogers, Kilpatrick, Perry Lake, Perry and Blakeley mines, with vein widths reported of between 1.0 and 1.6 m.

Barite

Between 1885 and 1948, 9,899 tons of barite were shipped from Ontario operations. This ore was extracted by surface mining of high-grade veins by manual methods, including hand-cobbing, at McKellar Island (Thunder Bay area), Langmuir Township and Penhorwood Township in northern Ontario and in North Burgess Township in the southeastern part of the province.

There is only one current producer of barite in the province. Extender Minerals of Canada Ltd. began operations in 1967 and has produced approximately 200,000 tons of barite since that date from a number of veins in the Matachewan area of northeastern Ontario. Ore is extracted from four sub-parallel veins in Yarrow Township, one vein in Penhorwood Township and one vein in Cairo Township. Production from a vein deposit in North Williams Township, in the Shining Tree Area, is expected to commence in 1991.

After originally being worked from surface, the veins are now mined by Extender Minerals by underground methods, producing a total of approximately 25,000 short tons of ore per annum grading 50 to 60% BaSO₄ prior to treatment. The barite ore is partially upgraded at the mines sites and then trucked to a treatment plant in Matachewan. The ore is dried and finely ground to -45 µm at the plant; the product, grading 93 to 97% BaSO₄, is bagged for sale in mineral filler markets.

Table 8 summarizes barite production in Ontario to the present day.

Table 8
Barite Production in Ontario
(Modified after Guillet, 1963)

Period	Shipments (tons)
1885-1887	4,564
1888-1890	2,942
1892	315
1894	1,081
1918-1948	995
1976-present	200,000 est.

Occurrences in Northwestern Ontario

Barite and fluorspar occurrences are concentrated along two fault zones west of Thunder Bay and along the Archean-Proterozoic unconformity in the Dorion area. Another concentration of barite veins is found in the Mazokama Bay area near Nipigon. The most significant known deposit of barite, in terms of tonnage, is the stratiform occurrence in the Hemlo Belt east of Marathon.

Fluorspar locations are documented near Rosspoint, Lake of the Woods, Sturgeon Lake (northeast of Ignace) and also in association with quartz-molybdenite veins at other properties. The largest occurrence of fluorspar to date is reported within the Springpole Lake carbonatite near Red Lake.

The occurrences in Northwestern Ontario are shown in Map 2.

Thunder Bay — Dorion Area Barite/Minor Fluorspar

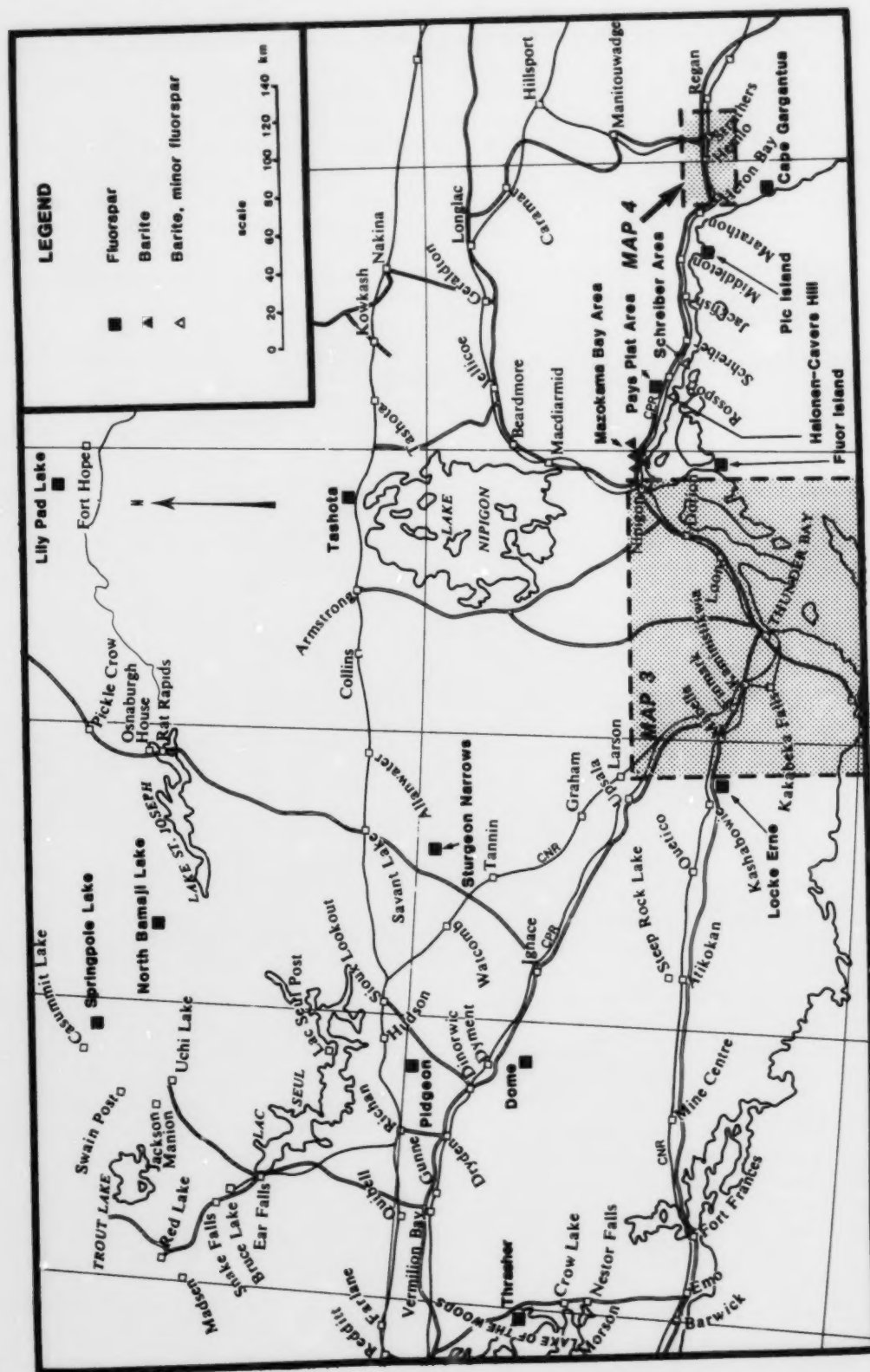
Calcite and barite are the major constituents of two parallel, northeasterly-trending zones in the Thunder Bay Area. The presence of fluorspar appears to be largely restricted to the northern system. The veins of both zones contain minor amounts of silver that was recovered in the latter part of the 18th century. The Dorion area is characterized by a number of lead and zinc-bearing barite veins of similar orientation to that of the northern vein-fault system of the Thunder Bay area.

Occurrences in the Thunder Bay and Dorion areas are located in Map 3.

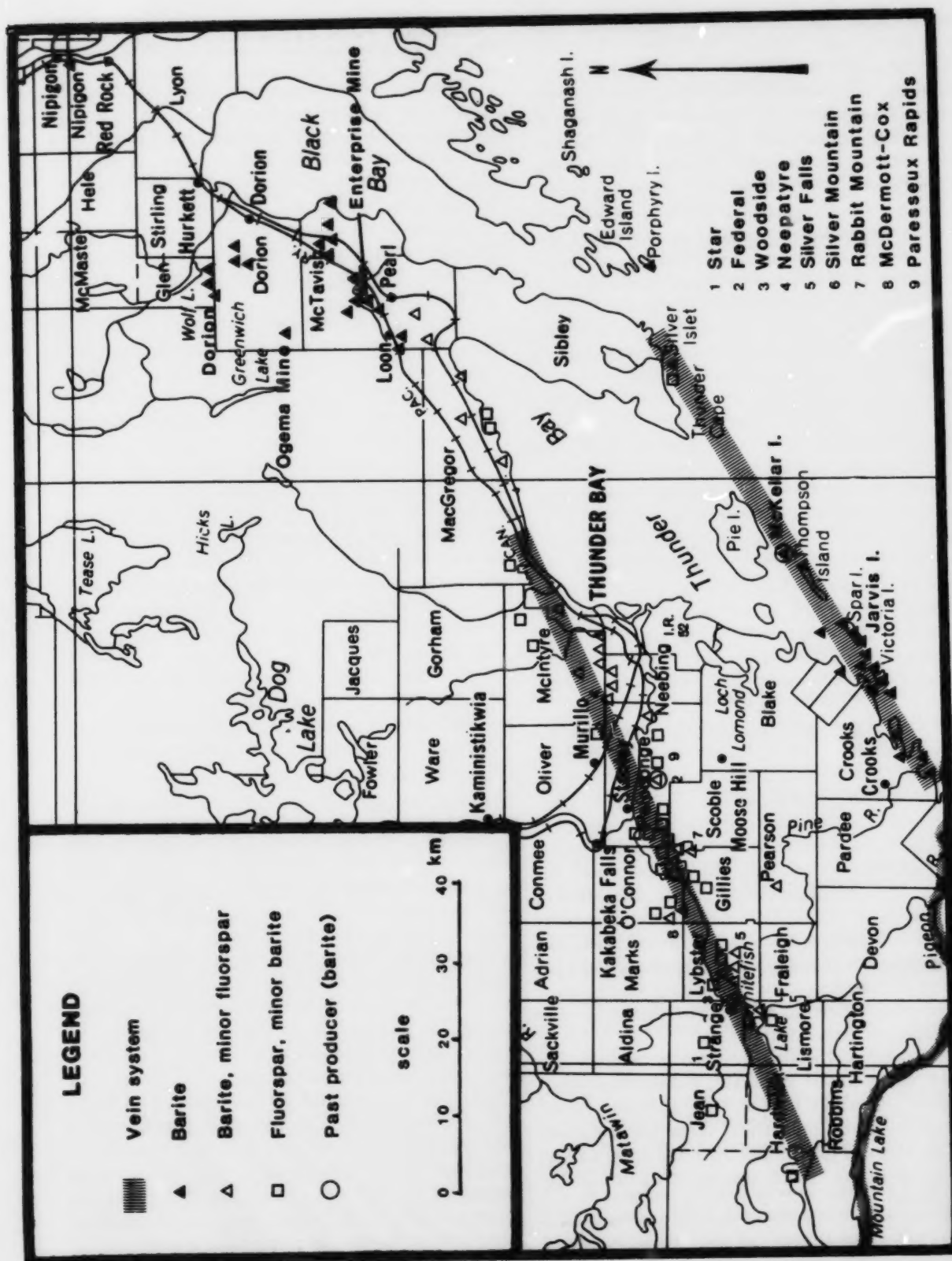
Northern Vein System: Thunder Bay Area

The northern vein system trends 067° and is generally vertically-oriented. It has, however, been documented to dip steeply to the north in some locations and steeply to the south in others. The veins occupy faults that cut the Logan diabase sills and middle Precambrian sedimentary rocks of the area. The being material consists of calcite, quartz, fluorspar, barite, minor disseminated sulphides (including pyrite, galena, sphalerite and chalcopryrite), as well as native silver and argentite. The vein material acts as a fracture in-fill, cementing pieces of the country rock within the fault zone.

Although most of the individual veins and faults that comprise the system are approximately 1 m wide, some veins such as those located on the Rabbit Moun-



MAP 2. Barite and Fluorspar Occurrences in Northwestern Ontario.



MAP 3. Barite and Fluorspar Occurrences in the Thunder Bay and Dorlon Areas.

tain, Neepatyre, and the Paresseux Rapids properties are up to 6 m wide.

Calcite within the veins is usually coarsely crystalline and white or occasionally pink in colour. The green and purple varieties of fluor spar occur individually or inter-banded within the veins. Yellow fluor spar is less common, but is reported to occur at the past-producing Federal Mine. Often the fluor spar surrounds calcite in a colloform texture. Quartz is ubiquitous in the veins that comprise the system occurring in transparent, white, smoky, amethyst, and rose varieties. The barite is generally white and coarsely crystalline.

Sulphides are disseminated throughout the vein material. Native silver occurs in fern-like and wire forms, while argentite occurs as films, sheets, and solid nuggets up to several ounces in weight.

Recent trenching and drilling has been undertaken in O'Connor Township on the McDermott-Cox barite showing (mining location: T144). The vein-fault zone can be traced on surface for approximately 450 m, and varies in width from 1.5 to 9 m. The vein consists of barite, calcite, amethyst, white quartz and fluor spar, with minor amounts of galena sphalerite. Barite comprises 20 to 60% of the vein material, while calcite accounts for between 10 and 20% and quartz accounts for between 30 and 40%. At the McDermott-Cox showing, the vein dips steeply to the north; however, on the adjoining property, mining location T143, the vein is reported to dip between 50° and 75° southeast (Tanton 1931).

The vein is exposed over a length of 46 m with an average width of 1.5 m on the adjacent T143 property. Tanton (1931), reports that the vein consists of coarsely crystalline, platy barite, white calcite, and quartz, with small amounts of green fluor spar and minor disseminated galena. Barite accounts for approximately one-third of the vein material and occurs in close spatial association to the calcite. At both the McDermott-Cox and T143 properties, the host rock is Animikie banded and oolitic iron formation, shale, and volcanic lapilli and ash tuff (Tanton 1931). The pinching and swelling of the vein and the varying proportions of vein minerals along strike make estimates of tonnage and grades difficult.

The largest vein widths recorded in the area are located on the Silver Mountain, Rabbit Mountain, Neepatyre, Paresseux Rapids, Federal, Silver Falls, Woodside and Star properties. These are scattered along the strike of the northern zone and are probably a reflection of the "pinch-and-swallow" nature of the vein system.

Southern Vein System: Thunder Bay Area

There are sixteen barite occurrences that comprise the southern zone and are hosted within the vertically-oriented, north-easterly-trending Pine River-Mount Mollie gabbroic intrusion. This intrusion contains two sets of vertically-oriented joints, one trending 135° and the other trending 80°. Almost all of the calcite-barite veins that comprise this system strike 315° and are either vertically-oriented or dip moderately to the northeast. The veins most likely occupy pre-existing joint fractures.

The veins of this southern zone vary from 1 m to over 20 m in thickness and consist predominantly of calcite and barite, with minor amounts of amethyst, fluor spar, pyrite, chalcopryrite, galena, sphalerite, cobaltite, smaltite, tetrahedrite, silver and argentite. The grades of the veins vary substantially over short distances, but are generally high, between 84 and 90% BaSO₄ where documented. The Jarvis Island vein strikes 135° and dips 40° to 60° to the northeast. Widths vary from 4.5 to 2 m over a distance of 244 m. At the southeastern end of the vein, it consists of approximately 80% calcite, 10% barite and 10% quartz. The northwestern end of the vein consists of approximately 50% barite. Minor amounts of fluor spar are recorded on the property. In the case of McKellar Island, the barite vein also strikes 135° but is vertical-oriented. Widths of the vein vary from 9 to 21 m over a strike length of 110 m. The vein material consists of approximately 50% barite with lesser amounts of calcite and quartz.

Dorlon Area

Tanton (1931) documented thirty separate lead-zinc-barite occurrences with the Dorion area. These occurrences consist of mineralogically-zoned, lead and zinc-bearing, calcite-quartz-barite veins, located along the unconformity separating the Archean Quetico gneiss belt and Middle Precambrian metasedimentary rocks of the Gunflint and Rove formations from the late Precambrian sedimentary rocks of the Sibley Group. The veins are characterized by a galena-calcite core, a sphalerite-quartz central zone, and a barite zone in the vein extremities along strike. The veins are similar in orientation and width to those of the northern vein-fault system in the Thunder Bay area. Franklin and Mitchell (1977) claimed that these occurrences constitute a distinct metallogenic entity, confined to the Sibley Group red bed basin, and that they are clearly distinguishable from the occurrences that constitute the northern Thunder Bay vein-fault system.

Of the thirty occurrences, only the Dorion, Enterprise and Ogema deposits were mined in the past for their lead and zinc contents. The veins typically consist of quartz, calcite and barite with minor fluor spar at these mines. The principal sulphide minerals are galena, sphalerite, pyrite, marcasite, chalcopyrite and chalcocite.

The vein system at the Dorion deposit comprises five separate veins extending for approximately 1525 m. The largest single vein is 2.4 m wide and extends along strike for 244 m. The barite occurs in the central portion of some veins and as distinct veinlets cross-cutting other portions of the vein system. Tanton (1931) reports one 1.3 m wide vein containing 20% sphalerite. Brecciated fragments of the wallrock can account for between 20% and 80% of the vein.

The Enterprise Mine is hosted within the Sibley Group sedimentary rocks. The vein system trends 065 to 075°, parallel to the Sibley Group-Archean unconformity. The 15 m wide system consists of approximately 10 cm wide veins, which occupy vertical joints within the Rossport formation. Fragments of wallrock account for less than 20% of the vein material.

The Ogema Mine is hosted within the Archean metasedimentary gneisses and pegmatites and contains veins that range from 2 to 5 cm in width.

Red Lake Area Fluorspar

The Springpole Lake property is located approximately 110 km northeast of Red Lake, within the Birch Lake Greenstone Belt, and geologically represents a small alkaline volcanic centre. Both extrusive and intrusive rock types, including fluorite-bearing, sovite-type carbonatite bodies, comprise what is referred to as the Springpole Alkaline Volcanic Complex (Barron et al. 1989).

Flows and pyroclastic deposits of the complex unconformably overlie the older Archean metavolcanic rocks of the area, and the complex is overlain by Temiskaming-type metasedimentary rocks. Porphyritic syenite and trachyte are the most abundant lithologies of the complex.

The fluor spar-bearing carbonatite intrusion accounts for only a small portion of the complex. It is exposed on surface at two locations but Barron et al. (1989) report a strike length of at least 1.5 km. The carbonatite is in sharp contrast with the surrounding, fenitized, country-rock breccias. Fluorspar occurs as fine disseminations and stringer veinlets within the carbonatite and adjacent fenitized breccias. In addition to calcite and fluorite, the carbonatite may also contain up to several percent barite and quartz. In the

exposed portion of the carbonatite, fluor spar averages 10 to 15 volume % of the rock.

The property is currently being investigated by Noranda Limited and Akiko-Lori Gold Resources Ltd., gold is the main mineral of interest. Recent diamond drilling on the property was reported to have intersected significant amounts of fluor spar in several holes, including one intersection of 32 m (drill width) averaging 27.9% CaF_2 .

Sturgeon Lake Area Fluorspar

The Sturgeon Lake area is located 76 km east of Sioux Lookout, within the Wabigoon Subprovince of the Canadian Shield. Within the immediate Sturgeon Lake area, Trowell (1983) has identified three alkalic complexes and proposes that all three are coeval and comagmatic.

The Wahl and Texmont properties are located with the Sturgeon Narrows Complex. Fluorspar occurs as fine disseminations throughout all rock types of the complex, accounting for up to 1% of the rock. Local concentrations of fluor spar are reported to occur along a sheared carbonatized zone on Sturgeon Narrows Island (Trowell 1983). Diamond drilling on the Wahl property by W.G. Wahl Limited in 1969 intersected fluor spar mineralization along with minor strontianite and vanadium mica. Diamond drilling by Selco Exploration Company Limited in 1970 did not locate any significant concentrations of fluor spar. Recent diamond drilling by Primrose Gold Resources in the area in 1989 also has not intersected significant concentrations of fluor spar. Trowell (1983) documented concentrations of fluor spar reaching a few percent in volume occurring along joints in the rocks located along the south shore of East Bay.

Although the Squaw and Bell Lake Complexes are similar to the Sturgeon Narrows Complex, Trowell has not reported the presence of fluor spar or carbonate (possibly carbonatite) zones in these two complexes.

Lake of the Woods Area Fluorspar

Fluorspar on the Thrasher Property occurs within a quartz-carbonate vein system, 1.3 m in width, that cuts felsic and lapilli tuff; the deep purple fluor spar forms fine-grained veinlets. The vein contains up to 15% fluor spar over short distances; the best intersections obtained in diamond-drilling, undertaken in 1964, reported visual estimates of 10% to 30% fluor spar over 3.5 m.

A geophysical survey, undertaken by Esso Minerals Canada in 1984, indicated that the fluor spar-bearing core of the Lobstick Bay shear zone cannot be traced

by geophysical techniques, and that the gold-bearing zone does not outcrop along strike to the east or west of the main zone (MNDM Assessment Files).

Nipigon-Schreiber Area Barite/Fluorspar

The Halonen-Cavers Hill fluorspar-barite property is underlain by an igneous complex composed predominantly of potassic feldspar-rich granite and granodiorite, cut by quartz-feldspar pegmatite veins and pods.

In addition to the purple fluorspar coating joint surfaces of the complex, three fluorspar-barite quartz veins occupy an easterly-trending breccia zone. Vein widths range from 1.3 to 18 m (Brown 1973).

The results of a reconnaissance mapping and water and stream sediment sampling program, undertaken by Asarco in 1973 (Brown 1973), indicate that the mineralized breccia zone has a series of isolated fluorspar showings covering a strike length of 915 m. Sampling of the vein over widths of 3 m range between 1 and 10% fluorspar with one sample yielding 23.11% CaF_2 over 3m. The results of the geochemical survey did not reveal any new fluorspar showings.

Drilling by E. Fornier in the area in 1982 and 1987 did not reveal any new fluorspar occurrences.

Three mineralized zones occur at the Pays Plat fluorspar occurrence informally known as the Chisholm Pit Zone, the Main Adit Zone and the Northern Creek Zone.

The Chisholm Pit Zone consists of a one metre wide quartz-calcite-fluorspar vein that occupies a steeply-dipping breccia zone trending 170° through Archean granite. The vein contains pyrite, galena and sphalerite as local sulphide-rich seams.

At the Main Adit Zone, a quartz-fluorspar-calcite vein occupies a breccia zone within the granite, and also contains local concentrations of pyrite, chalcopryrite and pyrrhotite. "Narrow" barite veins parallel the main vein.

A series of quartz veins containing disseminated to semi-massive pyrite are hosted within the granite gneiss at the Northern Creek Zone. Stripping and trenching was undertaken in 1987 and 1988 by Mr. Peter Moses. Fluorspar is reported to reach concentrations of up to 15% of the vein.

A number of barite occurrences are found within the Nipigon Bay area. The descriptions of these occurrences are derived from Tanton (1931).

In the northeastern corner of Nipigon Township, (lot 9, concession 3), barite veins, between 0.3 and 0.5 m in width, trend northeasterly through Archean granite. These veins dip 80° to the northwest and can

be traced for 50 m. The veins consist of approximately 90% barite, 5% galena, 4% sphalerite, 1% chalcopryrite and approximately 0.5 ounces per ton silver.

The following five occurrences are grouped in the Mazokama Bay region, of which the last three are within 5 km of Ozone Siding.

On claim TB 6038, a calcite vein containing minor amounts of quartz, amethyst and barite cements a 10 to 13 m wide easterly-trending, shatter zone hosted within a pegmatitic granite gneiss. This zone dips steeply to the north. Calcite accounts for approximately 80% of the vein material.

A vein system, consisting of a network of quartz and barite veinlets, cements a 3 m wide breccia zone in trending 003° through arenaceous tuff, on claim TB 4588. The vein material consists predominantly of white quartz, amethyst, white calcite and rose-coloured barite. Sulphides, including galena, pyrite, chalcopryrite and sphalerite, account for up to 3% of the rock.

On mining claims TB 3745/TB 4737/TB 3727, a vein system strikes 165° to 177° through a pegmatitic-granite gneiss. This vein cements a 10 m wide breccia zone that dips 70° to the north. The system consists of quartz and barite veins, less than 0.3 m in width. Where the western extension of this system is exposed, barite accounts for up to 70% of the vein material. White quartz amethyst and approximately 10% galena and sphalerite account for the remainder of the vein material. Minor chalcopryrite and pyrite occur disseminated throughout the vein.

A vein system, trending 087° and dipping 70° to 80° south, occupies a fault zone cutting pink tuff of the Sibley series at mining location TB 4533. The vein consists of approximately 1 m of vein material free of host-rock fragments and 1 m of brecciated country rock cemented with vein material. Tanton describes the vein as consisting of predominantly coarse white calcite, with lesser amounts of barite, white quartz, amethyst and purple fluorspar. Sphalerite occurs in local masses accounting for up to 3% of the rock. Fine disseminations of galena occur throughout the calcite.

A solid barite vein of up to 0.6 m is located about 3 km north of Ozone Siding. This vein forms part of a 3 m wide cemented breccia zone within granitic gneiss, striking 100° and dipping 68° to the north. Quartz and sparsely disseminated pyrite occur with the barite.

Hemlo Area Barite

The Hemlo area barite occurrences represent the largest known barite deposits in the province, containing over 6.5 million tonnes of barite.

The Hemlo area occurrences extend from the Hem-

lo gold deposit, located 7 km east of the town of Hemlo, to Pic River located 22 km west of the town of Hemlo, and currently consist of six known barite deposits, most of which are located on strike with or form part of the Hemlo gold ore zone. These locations are shown in Map 4.

The area is underlain by a highly deformed Archean metasedimentary and metavolcanic sequence as well as Archean granitic rocks.

The barite occurs in massive form or as thin wispy layers interlayered with recrystallized quartz, albite, pyrite, molybdenite and carbonaceous material. The barite horizons range from 1 to 3 m in thickness. Accessory minerals include green mica, carbonate, and magnetite-ilmenite (Gliddon 1985).

Hemlo Gold Deposit

In the Hemlo gold camp, barite is found at the contact between metasedimentary rocks and the felsic crystal tuffs, (Patterson 1984).

At the Williams, Golden Giant and David Bell mines, the baritic horizon forms part of the gold ore zone. Reported ore reserves of these deposits, as of February, 1990, were 34 million tonnes, 17 million tonnes and 7.1 million tonnes respectively. Friesen et al. (1985) reported that 10 to 13% of the ore zone in

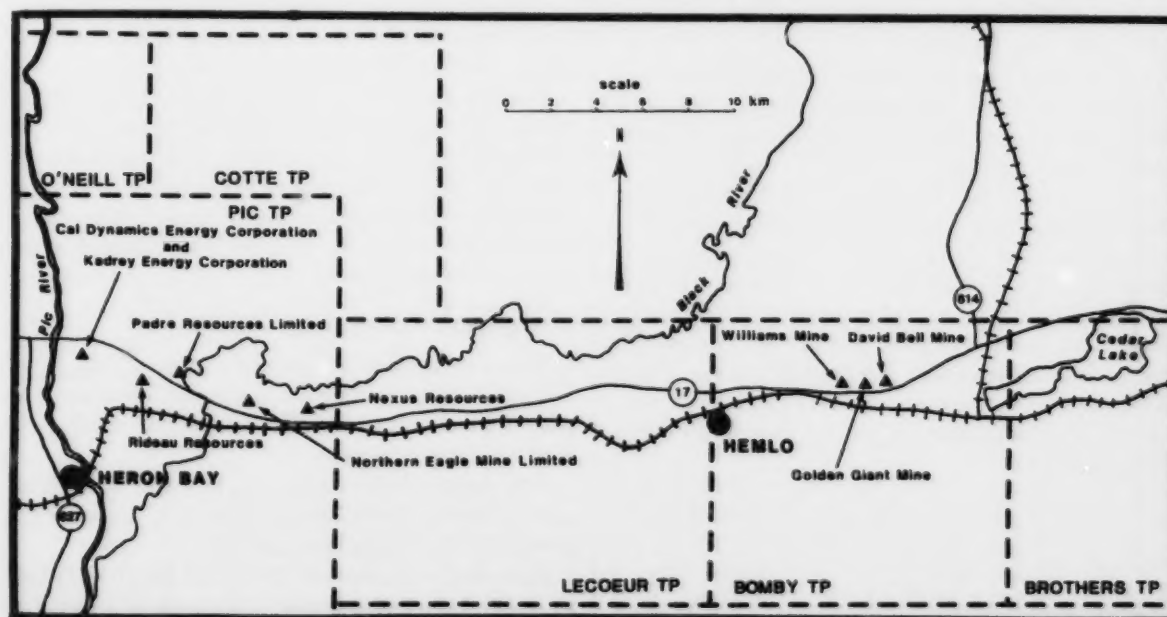
the William mine is barite, totalling approximately 3.4 to 4.4 million tonnes. The baritic portion contains quartz and minor amounts of pyrite and molybdenite. Approximately 14% of the ore zone at the Golden Giant Mine is barite and less than 5% of the ore at the David Bell Mine is barite. A total of approximately 6.5 million tonnes of barite is estimated to be in the ore zone of the three mines.

Western Occurrences: Hemlo Belt

The barite occurrences form a narrow zone apparently conformable on a regional scale with the local stratigraphy, occurring near the contact between the mafic metavolcanic rocks to the south and intermediate and felsic metavolcanic rocks to the north. The occurrences strike 095° and dips 80° to the south.

The Northern Eagle Mine occurrence is located 15 km west of Hemlo, and consist of a 1 to 2 m thick massive barite unit striking 110° and dipping 80° to the south. The pale grey to white barite contains thick carbonate-rich or pyrite-rich layers, which account for up to 10% of the rock. (Patterson, 1984).

Two types of barite are found on the property: 1) massive and predominantly monomineralic, recrystallized barite; and 2) laminated to wispy barite horizons, containing fine-grained pyrite and possibly



MAP 4. Barite Deposits In the Hemlo Area.

carbonaceous material, in dark grey to black streaks. The wispy to laminated barite horizon consists of layers of barite, quartz-albite and pyrite-barite-carbonate in gradational contact. These layers are generally less than 2 to 3 mm thick and have undergone recrystallization. Accessory minerals within the laminated barite horizon include green mica, calcite, magnetite-ilmenite and titanite.

The Padre Resources Limited property, located 17 km west of the town of Hemlo consists of a 1 m wide barite horizon, containing up to 70% barite along with minor amounts of pyrite, quartz, and carbonate (Patterson, 1984).

The barite horizon strikes 110° and dips steeply to the south. A green mica-schist, stratigraphically located beneath the barite, contains minor amounts of fluor spar. Cataclastic zones within the barite horizon contain fragments of wall rock and lamprophyres.

The massive barite is pale grey to white, fine-grained and displays a sugary texture. The barite occurs as recrystallized, anhedral aggregates within a fine-grained barite-albite-quartz matrix. Accessory minerals include pyrite, green mica, carbonate and titanite.

The Rideau Resources property is located 18 km west of the town of Hemlo. A barite-bearing chert horizon, intercalated with green mica-schist, strikes 110° across the property and dips 80° to the south.

Barite occurs along with chert, albite, minor carbonaceous matter, ankerite, calcite and pyrite as microcrystalline matrix material in the recrystallized, 3.5 m wide, chert horizon.

The Nexus Resources property, located 13 km west of the town of Hemlo, contains a 6 m wide, light grey baritic horizon intercalated with argillaceous metasediments (Mackie 1984).

A 2.8 m wide barite-rich unit outcrops near the claim boundary between Kadrey Energy Corporation property and that of the Cal Dynamics Energy Corporation, 22 km west of the town of Hemlo. The unit consists of light grey to white, massive barite, which grades into minor layers of pyrite-chert-carbonate. The horizon strikes 085° and dips 80° to the south. Three parallel barite units, up to 3 m in width, are spatially associated with the sericite-green mica schist (Patterson 1984).

Occurrences in Northeastern Ontario

Although several minor fluor spar occurrences have been reported at various sites, the region is best known for its worked vein deposits of barite; the sole current producer of barite in the province is located at Matachewan.

The occurrences of barite and fluor spar are shown in Map 5.

Yarrow Township Barite

The only currently active barite producer in Ontario is Extender Minerals Limited in Yarrow Township.

The property consists of four veins, occupying curved faults hosted within the Gowganda conglomerates and arkosic sedimentary rocks. These faults trend in an easterly direction, perpendicular to the northerly-trending Mistinikon River fault. The veins consist of approximately 60% barite with minor contaminants of quartz, calcite and hematite. The four veins, referred to as the Southern Vein, Main Vein, Northern Vein and Creek Vein, are either vertically-oriented or dip steeply (greater than 80°) to the north.

The veins tend to vary in width from less than 1 m to 10 m and often pinch out at both depth and distance away from the Mistinikon River fault.

Although much of the Main Vein has been mined, it originally reached widths up to 10 m and extended along strike for 61 m to a depth of at least 30 m. The minimum mineable width is currently 1 m.

Ore is removed from not only the four veins on the Yarrow Township Property but also from barite veins within the local area, including the Biederman-Browning Lake vein in Cairo Township and the Tionaga (Ravena) vein in Penhorwood Township. Removal of ore from the Tracy Lake vein in North Williams Township is planned in 1991.

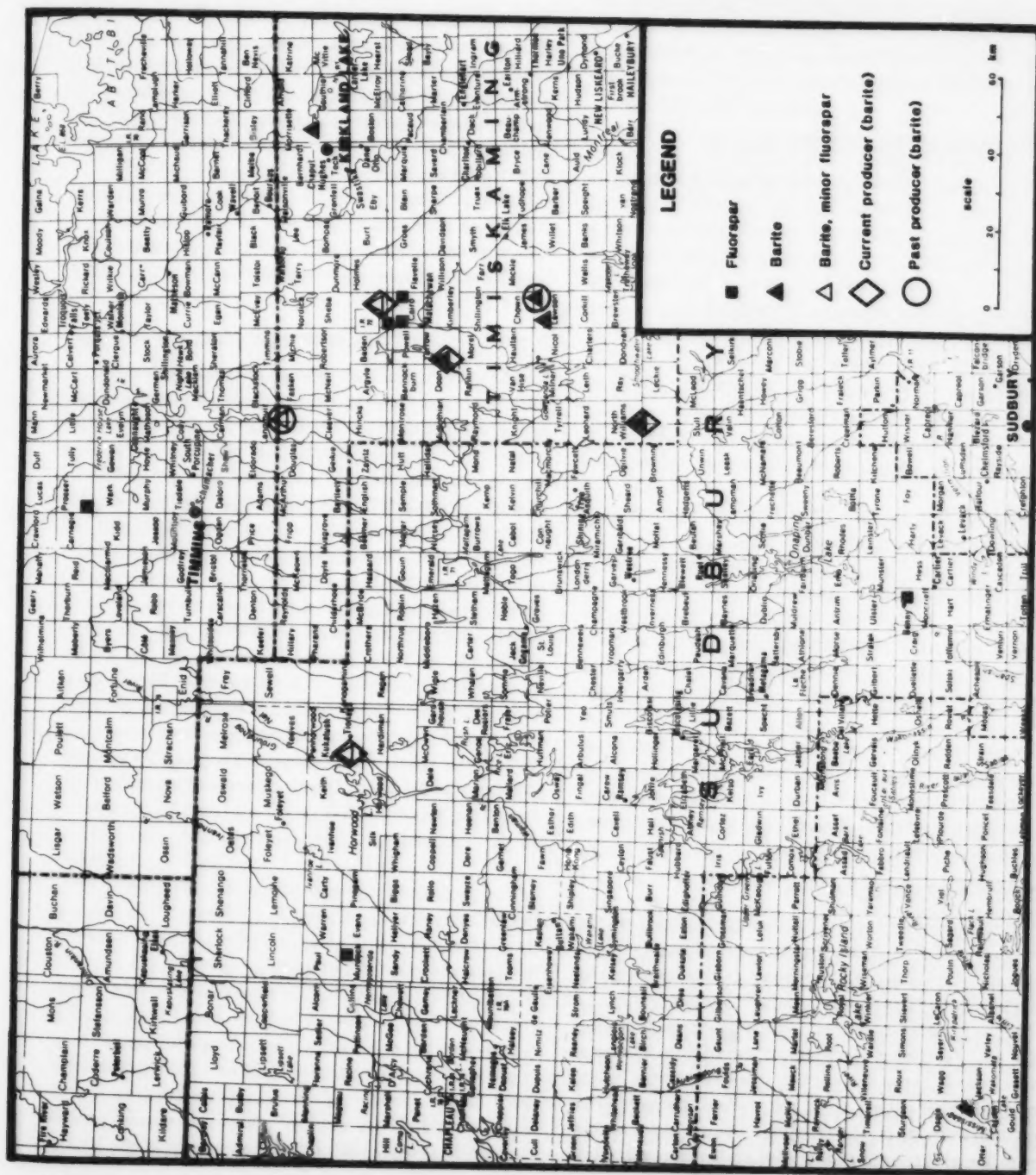
Langmuir Township Barite

The former Premier Langmuir Mine is located 32 km southeast of Timmins in Langmuir Township. The property contains two barite veins hosted within Kewatin mafic volcanics.

The main vein averages 1 m in width and strikes approximately 290° . Widths up to 2 m are recorded along the 366 m length of the vein.

A second vein, located 20 m from the first, ranges in width from 1 to 2 m over a distance of 24 m. The vein is approximately 61 m in length.

Both veins are vertically-oriented and consist of coarsely crystalline barite, calcite, minor quartz and



MAP 5. Occurrences of Barite and Fluorspar in Northeastern Ontario.

fluorite, with traces of galena, sphalerite, chalcopyrite and native silver.

Sampling by Peerless Canadian Explorations Ltd. along a 34 m length of the main vein yielded an average grade of 68.9% BaSO₄ over a width of 1 m. Pyke (1970) reports that 336 tons of ore material per vertical foot could be mined, assuming a minimum mining width of 1.6 m over a length of 183 m at a grade of 55% BaSO₄. An estimate of 250 tons per vertical foot could be mined from the second vein, at a minimum mining width of 1.6 m over a distance of 137 m for ore grading 55% barite.

Penhorwood Township Barite

The Tionaga deposit in Penhorwood Township is 4.8 km west of Tionaga Station on the C.P.R. Line north of Capreol. It is also known as the Ravena deposit. The property is underlain by pink Algoman granite, which has intruded mafic volcanics and sedimentary rocks including iron formation.

The main barite vein occurs in a northeasterly-trending vertical fracture, parallel to a weakly developed joint system within the granite. The vein reaches widths of up to 5 m, but averages 2 m over a distance of 30 m. The vein extends over a distance of approximately 150 m, although the central portion pinches out on surface.

A second vein located 12 m west of the main vein averages 0.6 to 1.3 m in width.

According to Guillet (1963), the vein consists almost entirely of barite. The barite is massive, white and generally fine-grained. Coarsely crystalline barite occurs scattered throughout the finer-grained matrix. Contaminants such as calcite and purple fluorspar tend to be restricted to a 15 cm zone adjacent to the wall-rock.

Spence (1922) reports that ten channel samples, taken across the main vein, average 95% BaSO₄. The second vein contains 98% BaSO₄. A 472 kg bulk sample analyzed by the St. Joseph Lead Company yielded 96.14% BaSO₄ and 1.89% SiO₂.

Cairo Township Barite

The Biederman deposit in Cairo Township is on the west shore of Browning Lake, approximately 8 km northeast of the town of Matachewan. The property is underlain by a hornblende syenite (Spence 1922).

The vertically-oriented, northwesterly-trending barite vein reaches a maximum width of 5 m. The vein can be traced for a distance of approximately 30 m. Purple fluorspar occurs along the walls of the vein. The main contaminant is quartz, which occurs as an accessory mineral throughout the vein and as a quartz-rich

zone reaching a maximum width of 0.75 m. "Small amounts" of galena, sphalerite and chalcopyrite give the barite a pinkish colour (Spence 1922). A sample, representative of the entire vein width, yielded 74.85% CaCO₃. Another sample, representing 2.5 m across the vein, assayed 90.50% BaSO₄ (Burrows 1918).

Lawson Township Barite

A vertically-oriented lens of barite strikes 75° through the Proterozoic Nipissing diabase, 1.7 km southeast of Longpoint Lake in Lawson Township. The lens is 18 m in length and 2.5 m in width. Vein material has been removed along its entire length to a depth of 2.5 m. The vein strike parallels one of the two joint directions in the diabase.

Spence (1922) claims that the vein is practically free of sulphides and fluorite. The vein consists of both fine and coarsely crystalline barite. Spence reports a grab sample assaying 98.03% BaSO₄, 0.70% SrSO₄, and 1.20% CaCO₃.

North Williams Township Barite

The Tracy Lake barite property contains two barite veins trending northeasterly through arkose of the Lorrain Formation. A trenching programme undertaken in 1977 by Extender Minerals Limited determined that the "A" vein had a strike length of 228 m while the "B" vein had a strike length of 457 m; portions of the vein with a width greater than 1 m were 137 m and 70 m in length respectively (Ministry of Northern Development and Mines Assessment Files). Some portions of the veins are up to 2.4 m in width. Drilling undertaken in 1977 by Extender Minerals indicated that the "A" vein dipped 82° south. Assays of 13 samples of vein material between the year 1975 and 1977 indicated that the content ranged between 95 and 99% barite, with one sample assaying 68% barite and another sample assaying 89% barite (Ministry of Northern Development and Mines Assessment Files).

Occurrences in Southeastern Ontario

The most numerous fluorspar occurrences in the province are found in the southeastern region, particularly within Madoc, Huntingdon, Cardiff, Monmouth and Ross townships.

Many of the barite vein deposits are located in Frontenac, Hastings and Lanark counties. Barite also occurs in association with some of the Madoc-Moira Lake fluorspar veins. Much of the barite in the region, however, occurs in relatively thin veins in comparison to those of the Thunder Bay and Matachewan areas of Northern Ontario and is not considered in detail in this section.

Map 6 shows the location of fluorspar and barite occurrences in southeastern Ontario. Guillet (1963, 1964) provides a detailed description of individual occurrences.

Madoc-Moira Lake Area

Mining was conducted in the area from 1905 to 1961 and, while no production has occurred since 1961, research into locating additional deposits has continued sporadically up to the present day. The most productive fluorspar veins within the province are located in the Madoc-Moira River area. They occur as fracture-fillings along two northwesterly-trending fissure fault systems covering a distance of approximately 154 km and spanning a width of approximately 5 km. The veins occur sporadically along both fault systems (Wilson 1929) as well as along joints and fissures within the country rock, which have undergone little movement (Williams and Thompson 1986). Although most of the fluorspar occurrences are located within the Palaeozoic limestone, the largest occurrences and most productive mines were located within the Precambrian marble and granite.

The vein deposits of the Madoc-Moira Lake area, and related geochemical/geological data, are shown in Map 7.

A survey to assess the fluorite potential of the Madoc and Cardiff Township areas was carried out between 1941 and 1951 by the Geological Survey of Canada. This survey involved making evaluations of the grades of ore remaining at a number of the past-producing mines in the Madoc area. Programs undertaken during this survey involved bulk sampling, diamond drilling and beneficiation testing. The results of the drilling program on the Keene, Perry, Coe, Rogers, Bailey, Johnston, McIlroy and Kilpatrick properties are summarized in Guillet (1964). The best

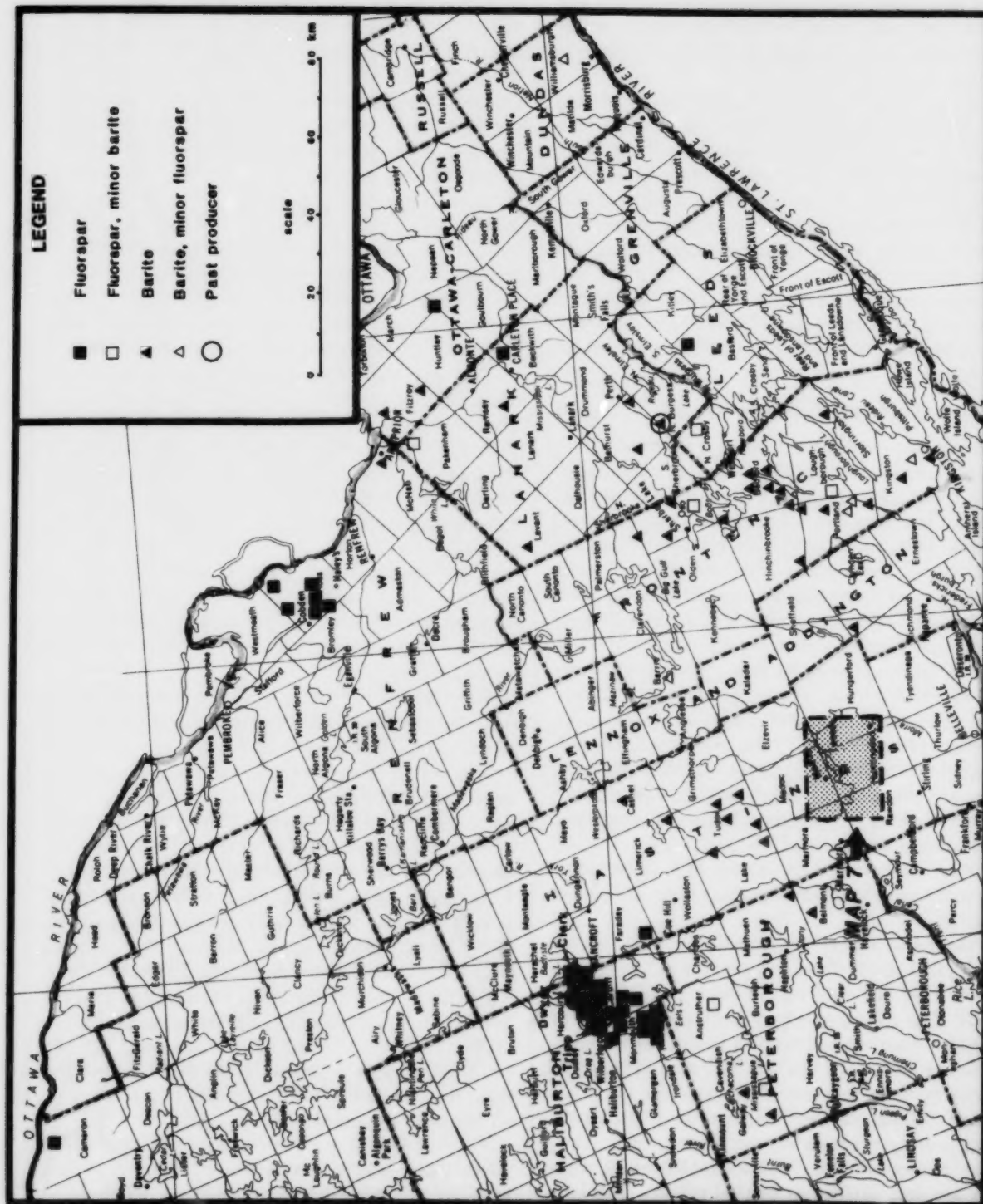
intersection was on the Keene property and comprised 2.96 m grading between 55 and 60% CaF_2 over a true width of 3.18 m. The thickest vein widths on the Perry property are located near shafts number 2 and 3, and only minor veinlets were observed in the core drilled on the Coe property. On the Kilpatrick property, vein material obtained in the core graded on average between 50 and 85% CaF_2 . Vein widths are estimated to reach their greatest true widths at 1.89 m, but much of the core was lost when drilling through the vein. A fluorspar vein can be traced over a distance of 335 m on the Johnston property.

The vein pinches and swells with maximum true width reaching 2.26 m with a grade of 45% CaF_2 . Only a minor amount of fluorspar was observed in the drilling of the McIlroy property. Vein material could be traced for 348 m across the Rogers property. The vein pinches and swells with a maximum true width reaching 1.24 m, grading 60% CaF_2 . Again, lost core was common, making true vein widths difficult to determine. On the Bailey property, the vein averages 7.07 m in width over a distance of 70 m; the material from the Wallbridge, Howard, Coe, Keene, Bailey and Johnston properties indicate that the ore can be upgraded to a product containing between 71 and 93% CaF_2 through simply jigging, tabling and calcine processing.

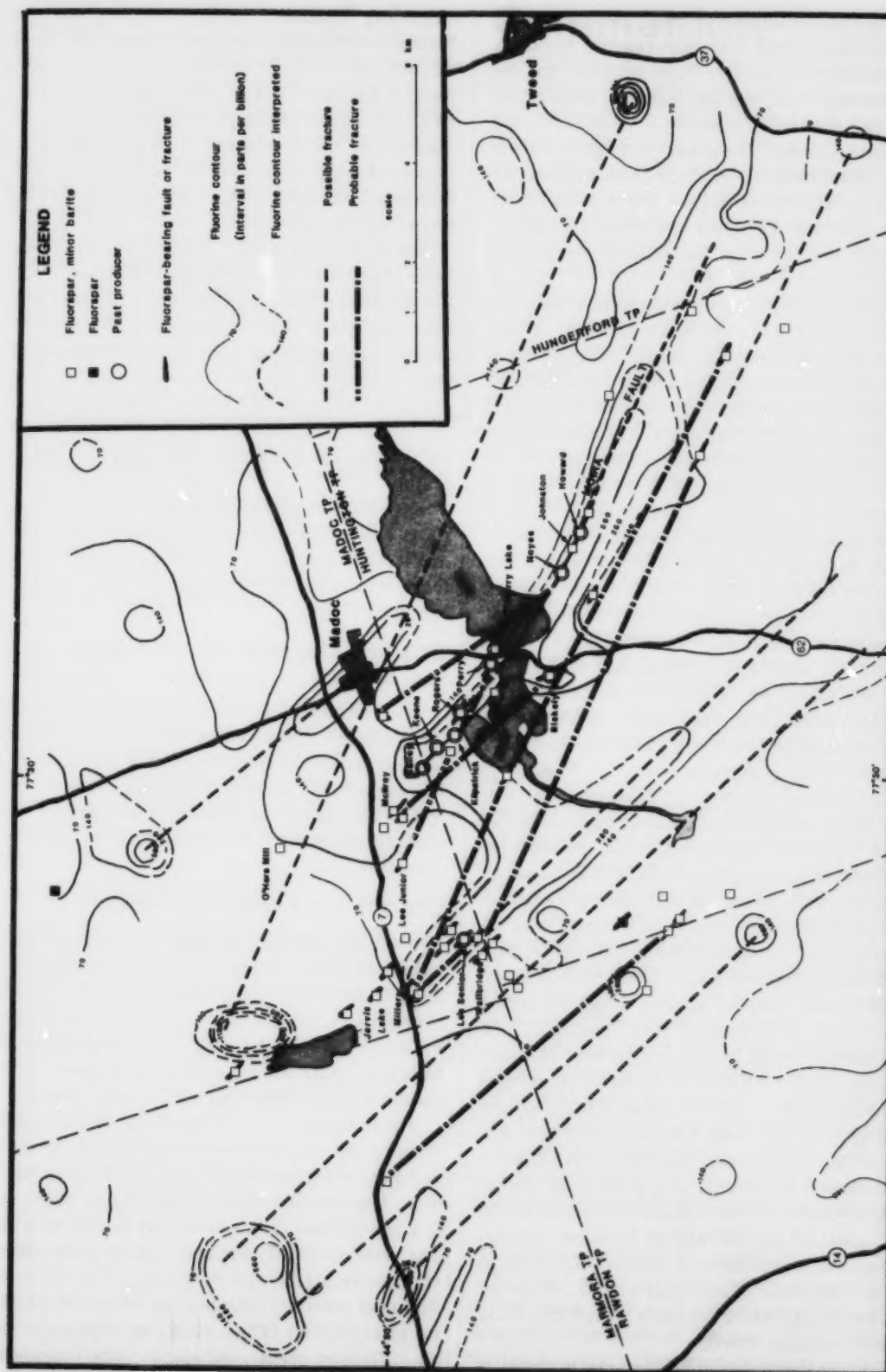
A number of regional normal faults in the area strike parallel to the major rift zones of the region. Surface traces of these faults tend to be distinctly curved, especially at junctions with other faults (Thompson and Williams 1987).

The fluorspar deposits of the Madoc area occur either as connected lenses, disconnected en echelon lenses or isolated lenses within faults or fractures in Palaeozoic or underlying Precambrian rocks. The largest ore bodies occur where the rock has failed along a single fracture (Guillet 1964). Wilson (1929) recognized the presence of two fault systems: one striking 115° and representing a predominantly horizontal fault motion and one striking 135° representing a vertical to sub-vertical fault motion. Because most of the veins with the second orientation were geographically removed from those belonging to the Moira Fault system, Wilson referred to this group as the Lee-Miller Group, which nearly all lie in concession 1, Madoc Township. Guillet (1964) proposed that the lenticular cavities occupied by the fluorspar-bearing veins were caused by the horizontal displacement of the walls on an undulating fault surface.

Recent mapping and geophysical work (Thompson 1989; Thompson and Williams 1987, 1988, 1989; Williams and Thompson 1986), confirms the existence



MAP 6. Barite and Fluorspar Occurrences in Southeastern Ontario.



MAP 7. Vein Deposits in Madoc-Molra Lake Area.

of the two distinct fracture systems. They concluded that displacement along fluor spar-bearing fractures was not generally significant. They propose that the fluor spar-bearing veins occupy fractures adjacent to faults and that the largest deposits have been located close to fault junctions. Their work has led to a revision of the classification of the Palaeozoic rocks in the area and to the identification of a major volcanics at the O'Hara Mill site. A number of the fractures trending 135° in the vicinity of the Moira fault system were also recognized.

It is uncertain whether the two fracture patterns were produced during one deformation event or two separate events; whether the emplacement of vein material took place during one or two episodes and whether one fracture system is filled with vein material of a higher grade over the other. The three largest producing mines — Rogers, Bailey, and Noyes — fall along both fracture systems, with the Noyes Mine being located at the junction of both systems.

Detailed geological and geochemical surveys were recently undertaken in three sub-areas within the immediate Moira Lake area (Dickson and Trinder 1989). The surveys confirmed the distribution of rock types previously determined by Hewitt (1968), Lalonde (1974) and Thompson (1986). The results of the geochemical surveys identified several coincident fluorine-barium-zinc target anomalies. Trenching of some of these targets failed to reveal any fluor spar-barite vein material on surface.

The vein material consists of fluor spar, calcite, barite and minor amounts of celestite, quartz, marcasite, pyrite, sphalerite and other sulphides (Guillet 1964); it tends to occur as either alternating bands or as irregular network partitions between vein cavities (Wilson 1929). Although the vein minerals tend to occur intermingled or interlayered in various proportions with no apparent order of precipitation, they often occur as two parallel mineral zones separated by a zone of fractured country rock. The zones are usually of uneven width, the separating zone of country rock ranging from a few centimetres to several metres in width (Wilson 1929). Lenses within the vein system range from less than 1 to 60 m in length and from under 1 to 5 m in width. Lenses of vein material tend to extend diagonally along the vein strike. According to Guillet (1964), there appears to be no consistent order of crystallization; however, quartz, sulphide minerals, and celestite tend to occur near to the wall of the veins. The banded distribution of fluor spar, calcite and barite indicates a rhythmic mode of deposition (Guillet 1964).

Although the composition of the vein material is

extremely variable, Guillet (1964) reports that the Madoc ore averages between 50 and 75% fluor spar. Calcite constitutes 25 to 50% of the veins and barite ranges between 5 and 40%, but averages 15%. Celestite, quartz and sulphide usually account for less than 5% of the vein material. According to Guillet (1964), the calcite content of the vein increases with both depth and narrowing of the veins, at the Howard, Keene and Bailey Mines.

Many of the "granitic" plutons within the Madoc-Moira Lake area are enriched in fluorine (Wu 1984). Phases of the Deloro pluton have fluorine contents that range from 1000 to 3660 ppm. The Barber Lake granite, located 20 km northeast of Sharlot Lake, and the Cheddar granite, located southeast of Bancroft, are both enriched in fluorine (Wu 1984). Lalonde (1974) has documented enriched fluorine contents in the marbles and siliceous rocks adjacent to the Deloro pluton.

Easton (1989) proposes that the Moira Lake granite is connected to the Deloro pluton at depth, and that it may be the source of some or all of the fluorine found within the fluor spar-calcite-barite veins in the Moira Lake area.

Cardiff, Monmouth, and Ross Townships

Fluor spar veins are hosted within the northeasterly-trending metamorphosed alkalic suite of intrusive rocks that extends over 100 km in length from Ross Township in the north to Glamorgan Township in the south. This suite consists of alkalic granite, alkalic syenite, nepheline syenite and mafic alkalic rocks (Lumbers 1982).

Cardiff Township Fluor spar

There are ten main fluor spar occurrences in Cardiff Township. Fluor spar occurs as a major constituent of narrow, lensoidal veins, hosted within the syenitic pegmatite and gneiss (Guillet 1964). Recent mapping by Bright (1983) has indicated that many of the fluor spar veins have a spatial association with carbonate dikes or lenses (possibly carbonatites).

The fluor spar in both Cardiff and Monmouth Townships occurs in fluor spar-calcite-apatite veins. These veins are described by Guillet (1964) as being irregular, discontinuous bodies, ranging in width from a few centimetres to 0.3 m and up to 100 m in length. The veins are highly variable in both composition and size along strike and down-dip. The dark purple fluor spar generally accounts for 20 to 30% of the vein material (Guillet 1964). Along with the major minerals of fluorite, calcite, and apatite, local concentrations

of hornblende, biotite, pyroxene, scapolite and magnetite can occur. The major minerals often occur as well-banded purple fluorspar, grey to cream-coloured calcite, and pale pink calcite (Satterly 1956). Post-depositional motion along the faults hosting the veins result in the development of a finely-banded, mylonitized calcite-fluorspar material.

Uranium-bearing minerals are present in the fluorspar veins at the Cardiff-Fluorite, Richardson, Tripp, Clark and Montgomery properties. Radioactive minerals have not been recorded at the Dwyer, Schickler and the Number 3 Zone of the Richardson properties (Guillet 1964).

Monmouth Township Fluorspar

A number of fluorspar occurrences are located in the east and southeastern portion of Monmouth Township. Most of these occurrences are small; however, diamond drilling carried out between 1971 and 1975 by Landair Exploration Limited outlined approximately 2 million tons of low-grade fluorspar ore in calcite-apatite-fluorspar veins, containing uraninite, uranophane and titanite, on a property extending between Concessions X to XII and Lots 33 to 35 (Martin 1983; Bright 1987).

This occurrence consists of two fluorspar horizons covering a length of 617 m and a width of 4 m. An upper horizon consists of calcite and fluorspar veins hosted within a granite pegmatite. The main vein of this horizon averages 2 m in width and contains between 20 to 24% CaF_2 (McConnel, 1977). A lower horizon consists of several narrow calcite-fluorspar veins occurring across a stratigraphic width of 5 to 9 m (Martin 1983).

Ross Township Fluorspar

Six fluorspar occurrences are hosted within the alkalic complex that underlies much of the western portion of Ross Township. All occurrences consist of fluorspar-calcite-apatite veins hosted within the syenitic gneiss (Satterly 1945).

Commentary

Although most of the showings and shallow workings of fluorspar and barite in the province have been well documented in the past, notably in the reviews by Guillet in the sixties, it is also true that such occurrences have rarely been further explored to investigate the possibilities of economic reserves.

Metals exploration programs in recent years have led to the incidental discovery of significant deposits in terms of volume, for example, Hemlo Belt barite and Springpole Lake fluorspar. Such discoveries encourage the view that concentrations at depth of potential economic interest for either of these two minerals remain to be identified in Ontario. Moreover, the present-day viability of working small deposits for specialty markets has been successfully demonstrated by the extraction of vein barite since 1967 by Extender Minerals of Canada Ltd. in the Matachewan area near Timmins.

This review has drawn attention to the more prominent showings, both individual deposits and clustered occurrences, which may merit further investigation. It has also noted the spatial association of several occurrences with alkalic igneous rocks and associated carbonatite intrusions that merits the attention of explorationists. On the basis of the geological information reviewed to date, the following areas are highlighted for their actual or potential resources:

Barite

Thunder Bay area, N.W. Ontario

Vein-type occurrences have been worked commercially during the last century for their barite content or for attendant silver values. The southern vein system, along a line of islands including Jarvis, Thompson, Spar and McKellar Islands, has recorded vein widths of up to 21 m. The grade of barite within the veins is high, between 84 and 90% BaSO_4 where documented. The only stated estimate of barite reserves is for McKellar Island at 50,000 short tons. The northern vein system is less well documented, but veins up to 6 m wide are noted, with probable grades of above 80% BaSO_4 for the barite in O'Connor Township.

A combination of three or more deposits in these vein systems could provide an overall resource estimate of better than 200,000 tonnes of barite.

Matachewan area, N.E. Ontario

Several known vein-type barite deposits, generally narrow, have been worked in an area centred on Matachewan to the south of Timmins. These deposits, and that of Tionaga to the west, were originally worked

from surface and are now mined by underground methods to produce up to 25,000 short tons per year with an estimated average grade of 50 to 60% BaSO₄; the grade of the barite contained in these veins, however, is often above 90% BaSO₄ on the basis of specific samples.

Hemlo area, N.W. Ontario

A substantial barite resource occurs in stratiform deposits which host economic values of gold. Three operating mines currently extract approximately 10,000 tonnes of gold ore per day (Table 9) from the underground workings. In original ore samples, a barite content of up to 14% BaSO₄ was noted, but current mined ore grades appear to be below 10% BaSO₄.

The ore also contains molybdenite, pyrite and stibnite. At present, only gold is recovered in the three operations. The processing plant residues, which are finely ground, are deposited together with water in adjacent tailings ponds. The gold ore reserves are large and are expected to sustain production at these operations for many years at current production rates.

Fluorspar

Madoc-Moira Lake area, S.E. Ontario

Numerous fluorspar veins, principally located within two vein-fault systems, have been worked from early in this century up to 1961. Total reported production from 1905 to 1961 of metallurgical grade fluorspar was around 110,000 tonnes. The veins, which include varying amounts of calcite, quartz and barite, have yielded samples of over 70% CaF₂, but an average grade of 40% to 60% CaF₂ is more probable. The literature does not provide any formal estimates of reserves for the individual deposits. An undetermined amount of ore is known to be present below mined depths and along vein extensions.

Red Lake area, N.W. Ontario

The Springpole Lake carbonatite body to the north-east of Red Lake includes significant fluorspar mineralization in terms of volume and grade, according to recently reported drilling results. This is a prominent example of fluorspar in association with

alkaline rock assemblages that is found across the province and encourages the targetting of this mineral in future exploration programs within these rock suites.

In summary, the great majority of individual occurrences of barite and fluorspar in the province are small vein deposits. In such cases, as demonstrated by the current operations of Ontario's barite producer, several of these deposits would be needed to provide adequate tonnage to a central milling operation to offer economic potential. Exploration in the short term should begin with the known vein systems in suitable proximity of prospects. Examples are the Thunder Bay vein-fault systems for barite and the Madoc-Moira Lake vein systems, as well as the occurrences in Cardiff and Monmouth townships for fluorspar in eastern Ontario. The available evidence for reserves in these vein deposits is scant; nevertheless, exploration targets of over 200,000 tonnes of barite in the Thunder Bay area and of over 500,000 tonnes of run-of-mine fluorspar ore from a variety of eastern Ontario deposits should be considered as objectives for speciality markets.

The two major known deposits in Ontario at the present time, in terms of indicated or proven volumes, are both gold properties in northwestern Ontario. The Springpole Lake gold prospect is still in the exploration stage, but significant fluorspar values will contribute to the economic evaluation of the property. The gold ore zone mined at Hemlo includes substantial quantities of barite. In light of strong regional market demand for each of the industrial mineral commodities for high-value chemicals production, it would be opportune for mining companies to review the present economics of by-product recovery potential for such minerals.

Table 9
Hemlo Area Daily Gold Ore Production

Golden Giant Mine	Hemlo Gold Inc.	3000 t/d
David Bell Mine	Teck-Corona Corp.	1100 t/d
Williams Division	Corona Corp.	6000 t/d

3. Options for Barite Mineral Production

Existing Production

Production of barite is currently limited to one company in the province. The company, Extender Minerals of Canada Ltd., produces barite ore from two mines in North-Eastern Ontario in the townships of Penhorwood and Yarrow from underground vein deposits (Andrews and Collings 1990; Collings and Andrews 1988a; Guillet and Kriens 1984). Mining methods are simple and low-key with a minimum of personnel. Approximately 25,000 (short) tons per annum of barite ore is partially upgraded at the mine sites, then trucked to a finishing plant in Matachewan. In this plant, the ore is dried and finely ground prior to bagging for sale in the mineral filler industry. The finished grade of barite is approximately 96% BaSO_4 . Ore produced from the two mines is between 50 and 60% BaSO_4 before treatment.

This operation has been continuous for a number of years and seems to fit a market niche, probably with long term contracts. It is probable that the deposits being worked could sustain a higher level of production if demand were proven and following some extra development of the underground workings or adjacent veins not presently being worked. The grade of material being sold is suitable as feedstock for a barite chemicals plant. It is not known what level of recovery is maintained in the upgrading process.

Production Options

A major use of barite is for drilling mud and this demand is met by a number of large volume, low-cost producers. Although the specifications for drilling mud barite are a little less rigid than for chemical grade barite, production of drilling mud grade material from Ontario sources is not considered to be practical due to the type of mineral resources and the implied control of the market by the existing producers.

A possible market is considered for up to 30,000 tonnes per year of chemical grade (92 to 96% BaSO_4) barite, as feedstock for a chemicals plant producing a range of barium compounds. This demand could be satisfied by:

- A single mill producing 30,000 tonnes per year of finished barite
- Two or more mills sized for smaller production from different areas in the province
- A single mill producing 30,000 tonnes per year of barite as a by product of the Hemlo gold mines.

The accepted specifications (Griffiths 1988) for chemical grade barite are given in Table 10.

An average of 94% BaSO₄ is considered in the following production discussions. These options are examined as follows:

30,000 tonnes per year Barite Mill

The Thunder Bay area appears to have the required in-situ ore grades and volume of deposits necessary to support a processing plant producing 30,000 tonnes per year of finished (average 94% BaSO₄) barite. An area reserve of at least 150,000 tonnes (of equivalent contained barite) would be required to initiate development of a project.

From the data presented in available reports, it seems unlikely that a single vein deposit could sustain this level of production.

After allowing for average mined ore grade and mill recovery, a mill feed rate of 47,000 tonnes per year would be required.

The deposit on McKellar Island has a stated reserve of 50,000 (short) tons (Collings and Andrew 1988a), but extraction rates would be limited by access to the site and the few possible working places on the surface of the small island. Possibly an underground operation would allow a higher production rate but development would be costly. An individual production rate of 10,000 to 15,000 tonnes per year of ore may be attained with surface workings. The neighbouring islands (Spar, Jarvis, Thompson) have similar deposits but these are not as well defined and if anything have narrower veins thus limiting production rates. It is possible that silver might occur in the barite vein structure and could be recovered during processing by gravity separation methods.

The vein deposits of O'Connor Township and the surrounding area offer easier access pending rights of way and ownership obligations. The veins here are narrower than on the islands but apparently contain high grade barite.

Due to the fairly short distance between the island and O'Connor Township deposits, a proposed mill for 30,000 tonnes per year production could be located centrally to treat ore trucked from two or more min-

ing locations. Ore from the islands would have to be transported across water by barge or possibly trucked over ice bridges during a brief period in mid-winter. The location of the mill would be selected to take advantages of existing highways, services and suitable land for the plant site and tailings disposal.

Based on information concerning the deposits and preliminary test programs at CANMET (Andrews and Collings 1990), the processing of the ore from these deposits would be simple and low cost. Previous production of barite depended on careful extraction from veins combined with hand sorting. CANMET studies of numerous samples showed that gravity separation alone was not always sufficient to obtain a satisfactory concentrate grade. In order to allow treatment of various deposits and to minimize manual upgrading, a combination of gravity concentration and flotation appears to be required. Grinding of gravity rejects prior to flotation will allow a maximum recovery of the barite from the ore.

In the proposed plant, initial size reduction of mined ore is followed by recovery using jigs and tables, followed by grinding and flotation of the gravity circuit tailings. Iron containing minerals will be removed from the combined gravity and flotation product by high intensity magnetic separation and the final product will be dried sufficiently to allow transport by truck to the proposed chemicals plant. Any excess production is exported. This flowsheet is illustrated in Figure 1.

The two other areas of potential barite production are not considered to be as attractive for the siting of a 30,000 tonnes per year production mill. The Matatchewan area mines probably have sufficient reserves but at the lower mined grade of ore, a mill feed rate of 80,000 tonnes per year would be required. A typical flowsheet for this type of ore is shown in Figure 2. It is doubtful if this level of production could be easily obtained in addition to current activities. A substantial development program would be required ahead of the production period. The deposits in the South-Eastern part of the province are small, of varying grade and a substantial program of exploration would be required to determine if available reserves could sustain the desired production rate.

Two or More Mills

The siting of at least two mills to produce an aggregate of 30,000 tonnes per year of finished barite appears feasible. The mills would be situated close to the mineral deposits and would suit the obtainable mining production rates. A disadvantage is the higher unit processing cost per tonne of product. For this

Table 10
Specifications for chemical grade barite

% BaSO ₄	92-96 (lump)
% BaSO ₄	96-98 (flotation conc.)
% CaF ₂ (max)	0.5
% SrSO ₄ (max)	1.0
% Fe ₂ O ₃ (max)	1.0

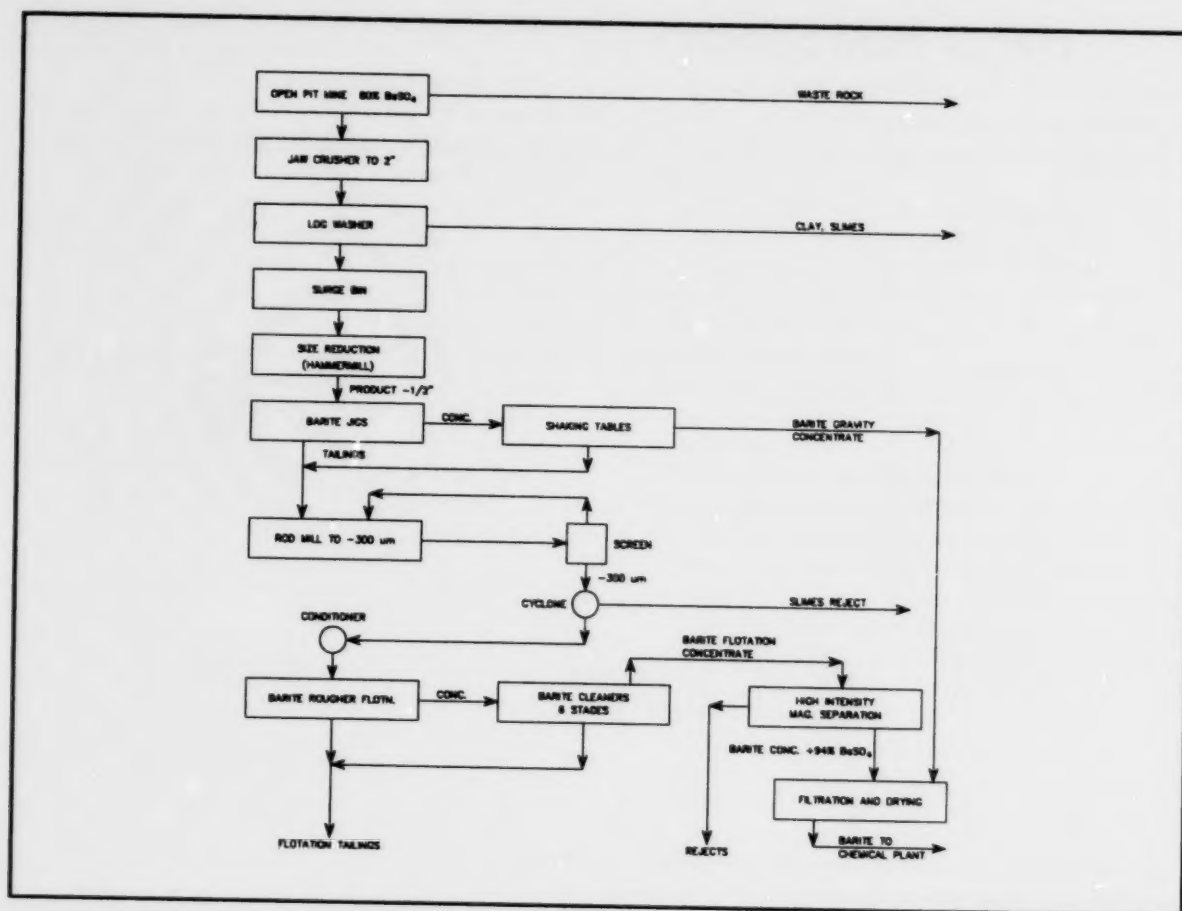


Figure 1. Barite Recovery from Vein Mine - Open Pit.

reason the study considers two mills only, each rated at 15,000 tonnes per year of barite concentrate. A probable location for the two mills is one in the Thunder Bay area and one in the Matachewan area. This is premised on the possibility of expanded mining capacity from the current operations near Matachewan or development of other deposits in that area.

The overall production cost of barite will be higher than in the first option due to the implied additional transportation cost of barite to the chemicals plant, which would be situated either centrally or close to one of the producing areas.

By-Product Mill

The production of 30,000 tonnes per year of barite as a by-product from the existing gold mines in the Hemlo areas is considered. One of the mines (Golden Giant Mine of Hemlo Gold Inc.) produces a sufficient quantity of ore to sustain this proposed production. Barite would be recovered by processing a portion of

the present gold mine reject (tailings) stream which is being discharged to a tailings disposal area.

The grade of barite in the existing tailings stream is low and assumed for this study to average 8% BaSO_4 . The tailings solids also contain minor quantities of pyrite, molybdenum sulphide and smaller amounts of other metal sulphides plus mica. Processing methods must remove these deleterious minerals in order to produce the required high grade barite concentrate. Hemlo Gold has installed and operated briefly a molybdenum recovery circuit within the existing mill but operation was curtailed due to unfavourable economics. The obvious advantage for the proposed barite recovery plant is that all ore mining and size reduction is conducted as part of the gold recovery operation.

The mill cost of barite production would still be high since approximately 705,000 tonnes per year of gold mill tailings need to be processed to yield the required 30,000 tonnes per year of barite. This is a

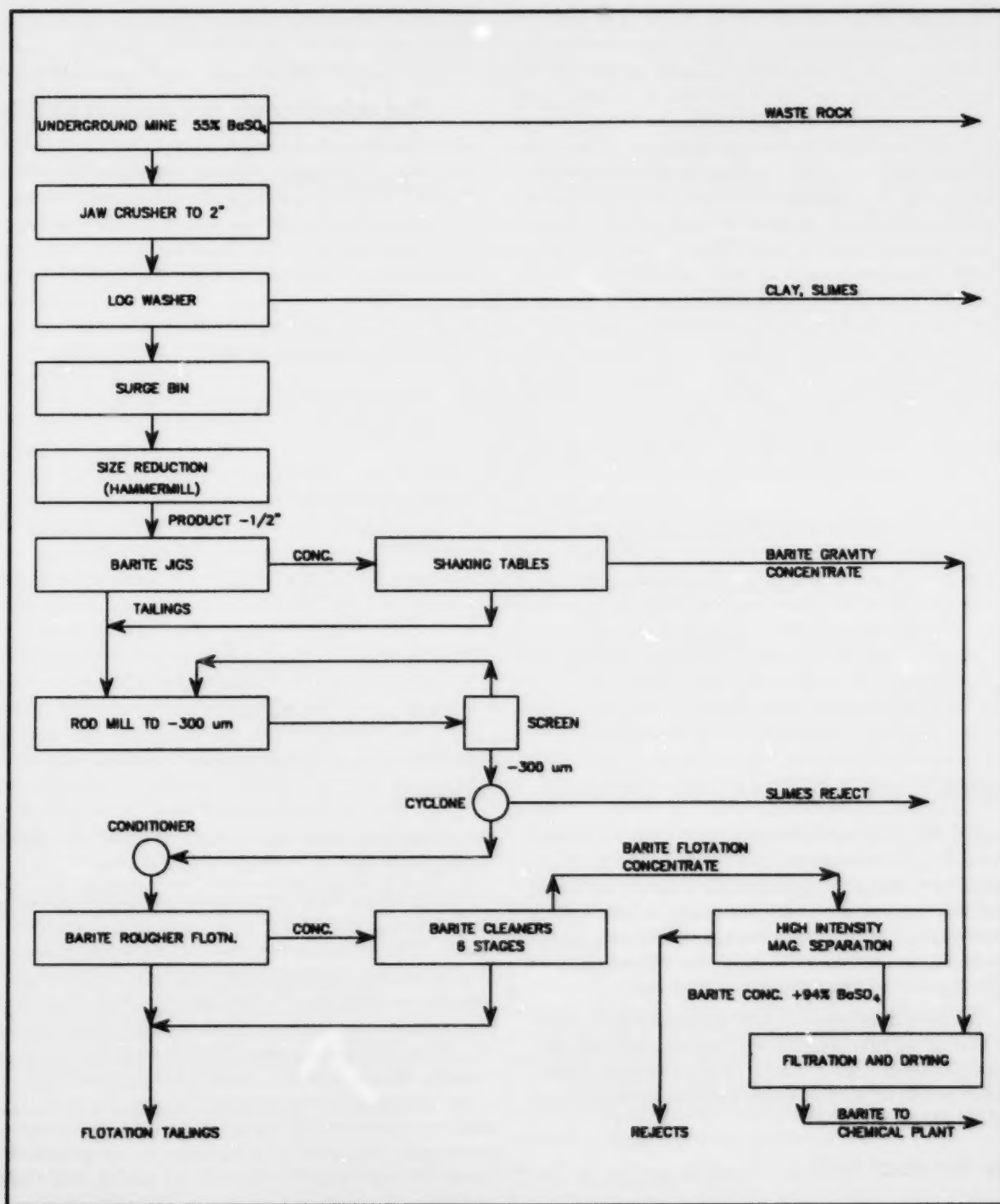


Figure 2. Barite Recovery from Vein Mine - Underground.

substantial quantity, equivalent to a mill capacity of about 2,000 tonnes per day.

In order to produce a clean, high grade barite concentrate, the flotation process would be employed. Recovery by flotation of pyrite, molybdenum and other metal sulphides will be necessary prior to the barite flotation stage. Final cleaning by acid leaching will probably be required to eliminate iron contamination. The selected process is shown in Figure 3. Although not specifically included in this study, costs associated with possible royalties and changes to existing disposal systems may be incurred. The recovery of barite will also remove from the gold mill tailings a major source of material available for backfilling underground workings. While Hemlo Gold does not presently recover material for backfilling it is possible that this may be a future consideration.

Production Costs

The costs of barite production have been estimated on the basis of the three main production options previously described. The costs comprise two main categories:

- Pre-production capital costs for mine development, mill construction and services,
- Operating cost during the production phase including transportation of ore and concentrate.

Mining costs are developed on the basis of a contracted mining operation using typical rates for small open pit or underground mines, thus reducing capital requirements. The major capital expenditure in each case is for construction of a milling facility which includes services. Mill sizes equivalent to annual production levels of 15,000 and 30,000 tonnes per year are examined for each probable producing area.

Direct operating costs include mining, ore transportation and milling. Milling costs are derived from estimated labour costs plus processing costs (power and raw materials), the latter based on flowsheets and chemical consumption rates proposed in the CAN-MET testwork (Collings and Andrews 1988a).

Added to the direct operating cost of barite production is the cost of capital expenditure recovery and an allowance for product shipping. It is assumed for comparison that capital expenditures will be recovered during the first five years of production. Product shipping to a chemicals plant is assumed to be by normal highway type truck but depends primarily on site and market locations.

Open Pit Vein Production

A preliminary design for the processing plant and the preliminary estimate of operating cost is premised on the assumed criteria listed in Table 11.

This is typical of a Thunder Bay area plant described previously. The small proportion of operating time is

Table 11
Preliminary Operating Costs for an Open Pit Barite Operation

Mined ore grade	(% BaSO ₄)	80
Barite recovery	(%)	75
Product grade	(% BaSO ₄)	94
Annual production	(tonnes)	30,000
Seasonal operation	(months)	8
Days per week		5
Hours per day		16

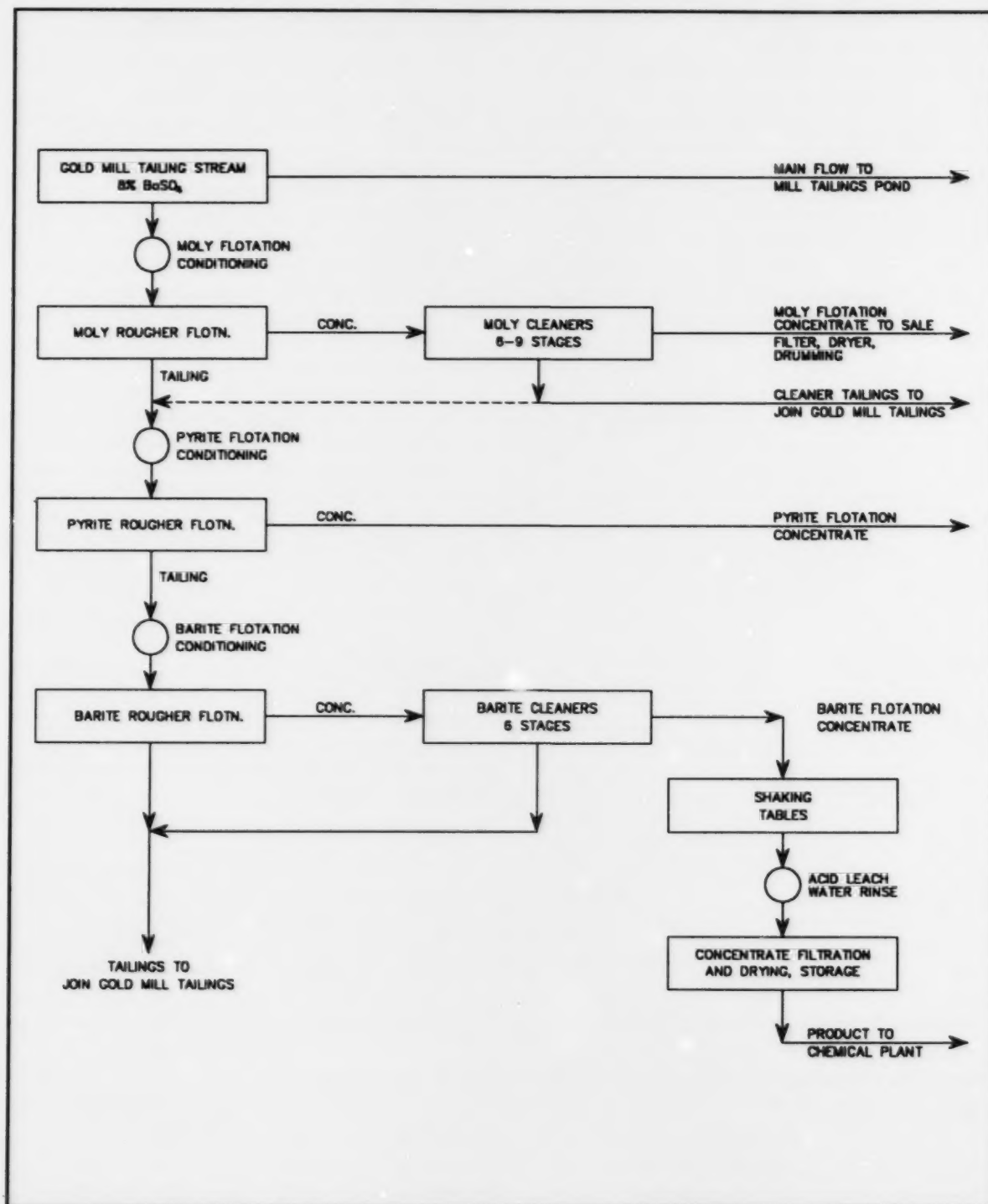


Figure 3. Barite Recovery from Mill Tailings.

Table 12
Mine and mill production cost summary
Barite mill, open pit vein mine

	ANNUAL COST, \$	UNIT COST, \$/t ore	UNIT COST, \$/t Product
Payroll	582,000	12.65	19.40
Reagents and Supplies	243,000	5.28	8.10
Maintenance Supplies	75,000	1.63	2.50
Power and Fuel	160,000	3.48	5.33
Contract Mining	644,000	14.00	21.47
Ore Haulage to Mill (40 km)	460,000	10.00	15.33
Insurance, taxes, etc.	50,000	1.09	1.67
General	115,000	2.50	3.83
Contingency	232,900	5.06	7.76
Direct Operating Cost	2,561,900	55.69	85.40
Capital Repayment (5 years)	600,000	13.04	20.00
Product Shipping (40 km)	78,000	1.70	2.60
Total Production Cost	3,239,900	70.43	108.00

NOTE: Milling Rate = 46,000 tonnes per year
 Product Rate = 30,000 tonnes per year

selected to suit seasonal production and handling of the open pit ore and to optimize the fixed labour costs.

The estimated capital cost for this facility is approximately \$3 million. Mining equipment is not included as costs are based on a contracted mining and ore haulage operation. Preliminary information on the sizes of major items of equipment and typical purchase costs are provided in Appendix A.

The estimated production cost is developed in Table 12, resulting in a direct operating cost of \$85 per tonne of barite product. Indirect costs for capital recovery and product shipping are estimated to bring the overall production cost to approximately \$108 per tonne of barite. Silver may also be recovered when working favourable vein deposits and sold as a by-product, thereby reducing net operating costs.

A total of 14 personnel are required for operation

Table 13
Estimated costs for a 15,000 tons per year open pit operation

Capital cost	\$3 million
Direct operating cost	\$108 per tonne barite
Overall production cost	\$151 per tonne barite

of the plant, plus contractors engaged in mining and trucking.

The capital cost of a facility to produce 15,000 tonnes per year of barite is estimated to be similar, based on the use of an identical plant but at reduced operating time. The operating cost will be slightly higher due to the effect of the lower production rate on fixed costs.

At 15,000 tonnes per year capacity, the total estimated costs are shown in Table 13.

Underground Vein Production

A similar processing plant is proposed for upgrading underground ore from a typical North-Eastern Ontario producer. Table 14 illustrates the criteria employed.

Operation during a 12 month per year period is proposed due to the higher ore treatment rate and to avoid stockpiling ore during winter periods.

The estimated capital cost for the facility is again approximately \$3 million. This plant can be identical to the plant employed to treat the open pit vein deposits. A preliminary estimate of direct operating cost is \$159 per tonne of barite, with an overall production cost (including capital recovery) of \$242 per tonne barite produced. This is shown in the Table 15. It has been assumed also that the product will be

Table 14
Preliminary operating costs for an underground barite operation

Mined ore grade	(% BaSO ₄)	55
Barite recovery	(%)	70
Product grade	% BaSO ₄)	94
Annual production		30,000
Seasonal operation months		12
Days per week		5
Hours per day		16

shipped to a chemicals plant located either in North-Eastern Ontario or in Southern Ontario. A total of 15 personnel are required, plus contractors engaged in mining and trucking.

At the lower production rate of 15,000 tonnes per year, which may be more applicable in this case, the capital cost remains as \$3 million and the overall production cost increases to \$274 per tonne barite.

Two or More Mills

The concept of two or more mills producing an aggregate of 30,000 tonnes per year of barite may suit the proposed production rate from the presently known deposits. On the assumption that a mining/milling

Table 16
Average Operating Cost for Two Mills

Capital cost (2 mills)	\$6 million
Operating cost (direct)	\$146 per tonne barite
Operating cost (overall)	\$212 per tonne barite

operation of the two types considered above may be combined, an average cost is shown in Table 16.

This overall cost implies the shipment of half of the production over a considerable distance to a chemicals plant located near one of the producers. Total employment related to the two plants is estimated to be 23, plus personnel engaged in contract mining and trucking activities.

By-product Recovery

A processing operation designed to recover 30,000 tonnes per year of barite from gold mill tailings in the Hemlo area needs to process approximately 705,000 tonnes per year of the tailings. The proposed plant will treat a portion of the current tailings stream, with design criteria shown in Table 17.

Continuous operation throughout the year is designed to match the gold mill operation. The option of recovering already deposited tailings is not con-

Table 15
**Mine and Mine Production Cost Summary
Barite Mill, Underground Mine**

	ANNUAL COST, \$	UNIT COST, \$/t ore	UNIT COST, \$/t Product
Payroll	734,000	9.18	24.47
Reagents and Supplies	328,000	4.10	10.93
Maintenance Supplies	50,000	0.63	1.67
Power and Fuel	184,000	2.30	6.13
Contract Mining	2,080,000	26.00	69.33
Ore Haulage to Mill (40 km)	800,000	10.00	26.67
Insurance, taxes, etc.	50,000	0.63	1.67
General	115,000	1.44	3.83
Contingency	434,100	5.43	14.47
Direct Operating Cost	4,775,100	59.69	159.17
Capital Repayment (5 years)	1,000,000	12.50	33.33
Product Shipping	1,485,000	18.56	49.50
Total Production Cost	7,260,100	90.75	242.00

NOTE: Milling Rate = 80,000 tonnes per year
Product Rate = 30,000 tonnes per year

Table 17
Design Criteria for By-product Recovery

Capital cost	\$3 million
Ore grade-gold mill tailings (% BaSO ₄)	8
Barite recovery (%)	50
Product grade (% BaSO ₄)	94
Annual production	30,000
Seasonal operation months	12
Days per week	7
Hours per day	24

sidered due to the difficulty and cost of working within the tailings pond areas.

It must be noted that, while the area is developed by the existing mining operations, a new independent facility would still require development of the site and installation of services. The exception would be if one of the existing gold producers installed a barite recovery plant as an adjunct to the present milling operation. This has not been considered for this study.

The capital cost of the facility is estimated to be approximately \$8.4 million. Preliminary information on the sizes of major items of equipment and typical purchase costs are provided in Appendix A.

The estimated production cost is developed in Table

18, giving a direct cost of approximately \$100 per tonne of barite product. The addition of indirect costs for capital repayment and product shipping brings the total production cost to approximately \$180 per tonne. Molybdenum sulphide may be recoverable for sale as a by-product, thereby reducing net operating cost.

A total of 17 personnel are required for plant operation and administration.

Table 18
Mine and Mill Production Cost Summary
Barite Mill, Gold Mill Tailings

	ANNUAL COST, \$	UNIT COST, \$/t ore	UNIT COST, \$/t Product
Payroll	835,000	1.18	27.83
Reagents and Supplies	955,000	1.35	31.83
Maintenance Supplies	300,000	0.43	10.00
Power and Fuel	393,000	0.56	13.10
Contract Mining	0	0.00	0.00
Ore Haulage to Mill	0	0.00	0.00
Insurance, taxes, etc.	100,000	0.14	3.33
General	105,000	0.15	3.50
Contingency	268,800	0.38	8.96
Direct Operating Cost	2,956,800	4.19	98.56
Capital Repayment	1,686,000	2.39	56.20
Product Shipping	757,200	1.07	25.24
Total Production Cost	5,400,000	7.66	180.00

NOTE: Milling Rate = 705,000 tonnes per year
Product Rate = 30,000 tonnes per year

4. Options for Barium Chemicals Production

Production Options

The majority of barium chemicals are derived from high quality barite ore, containing a minimum of 94% barium sulphate (BaSO_4), which is reacted with a carbon source (usually coal) at high temperature to produce barium sulphide, the precursor of a wide range of barium chemicals. Primary and secondary derivatives of the BaS that were identified as representing a potential commercial opportunity for Ontario's industrial minerals industry include the high demand derivatives BaCO_3 and BaCl_2 and lower volume, value-added BaSO_4 , BaO , BaO_2 , $\text{Ba(NO}_2)_2$, BaTiO_3 , barium stearates and barium ferrites.

Based on an overview of the market potential for these barium chemicals in Canada and the North-Eastern United States, it was decided to concentrate on the production of commercial quantities of BaS, primarily for captive use, BaCO_3 , primarily for sales, BaCl_2 , BaSO_4 , BaO and Ba(OH)_2 . Production of these barium chemicals in dedicated production facilities was considered to be the prime criterion although production in a multi-purpose plant was explored as a means of reducing overall production costs. The use of a multi-purpose plant offers the potential of producing additional low volume, value-added, barium chemicals to take advantage of short term market opportunities.

In all cases, processing options were selected to take advantage of the best available technology, including established and emerging technologies, to protect the environment by controlling harmful emissions and, if possible, to produce competitively priced final products. In particular, processes were selected to control sulphur emissions by the production of by-product Na_2S , a potentially valuable chemical in the pulp and paper industry.

Figure 4 depicts the various processing routes available to produce the various barium chemicals from barite/barium sulphide (Ullman et al. 1985) and highlights the routes selected for this study.

Production rates for the barium chemicals were established (Table 19) based on the potentially available Canadian and North-Eastern United States markets and the need to construct and operate a reasonably sized facility in order to produce competitively priced products.

A total of 30,000 tonnes per year of barite concentrate (94% BaSO_4) was assumed to be available from the mineral production facilities.

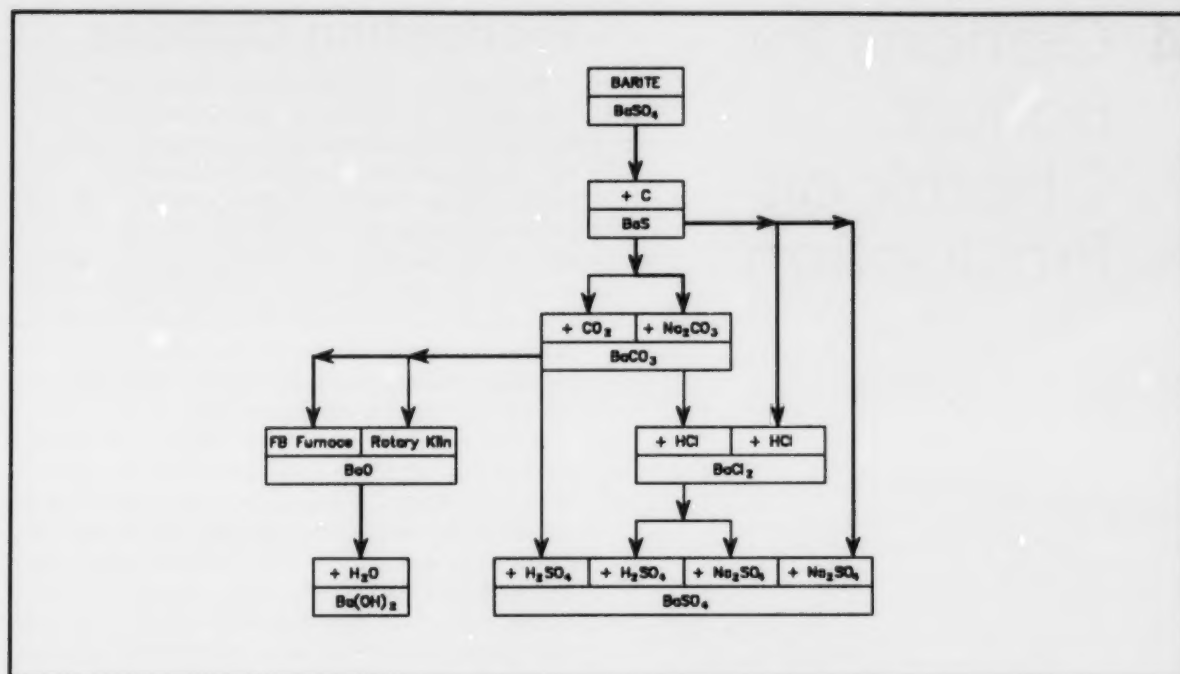


Figure 4. Production Pathways to Various Barium Compounds.

Barium Sulphide

Barium sulphide, the precursor of most barium chemicals, is produced from high quality barite (minimum 94% BaSO₄) by reduction with a source of carbon. The primary chemical reaction is:



The most popular process for the production of BaS is the rotary kiln process (Kirk et al. 1984; McKetta

and Cunningham 1976; Ullman and Gerhartz 1988; White 1949) in which the reduction reaction is carried out with coal or coke as the source of carbon in a supplemental fired rotary kiln at temperatures of 1000 to 1250°C. Purity of the barite ore must be high, with minimum iron and silicon concentrations, as these impurities tend to form insoluble barium compounds during the reduction process. A crude BaS (black ash), typically containing 75 to 90% BaS, is discharged from the rotary kiln.

Off-gases from the kiln contain particulates and SO₂ from the sulphur in the coal or coke used in the reduction reaction, from the kiln fuel and from side reactions that occur in the kiln. As a result, removal of particulates and SO₂ scrubbing are required to avoid air pollution problems and to meet applicable environmental emission standards.

Barite reduction to BaS with natural gas in fluidized bed reactors has been discussed in the literature (Kirk et al. 1984; Ullman and Gerhartz 1985) and is reportedly being carried out in the U.S.S.R. The fluidized bed process offers several advantages, including lower SO₂ emissions and the potential for the elimination of the scrubbing systems as the sulphur content of the carbon source and fuel is essentially zero. Additionally, the purity of the black ash product is potentially higher and lower grades of barite ore can be consid-

Table 19
Production rates for barium chemicals

BaS	20,000 tonnes per year
BaCO ₃ (sales)	12,000 average, 14,000 maximum
BaCl ₂	3,500 average, 5,000 maximum
BaSO ₄	1,000 average 1,500 maximum
BaO/Ba(OH) ₂ (as BaO)	1,500 average, 3,000 maximum

Table 20
Black Ash Analysis

Water Soluble BaS	75-90%
Insoluble Barium Compounds	5-17%
Inert Ash, SiO ₂ , Fe ₂ O ₃	5-8%

ered as no inert materials enter with the carbon source. However, insufficient data were identified to permit an evaluation of the economic feasibility of the process, compared to that of the rotary kiln process.

Black ash from either process is a grey/black powder that reacts readily with moisture and CO₂ in the air to release H₂S. Some black ash is packaged and sold to producers of barium chemicals but most is processed directly into other barium chemicals. The typical analysis for black ash is shown in Table 20.

Black ash produced in the kiln for further processing is wet or dry ground to a fine powder and contacted with water in a series of leaching tanks. The BaS is extracted into the water, forming a 25 to 30% solution of BaS. The aqueous solution is stored for further processing into other barium chemicals.

The undissolved residue or sludge, containing BaCO₃ and other acid-soluble barium salts, unconverted BaSO₄ and inert impurities, is temporarily

stored for further processing into BaCl₂. Discarding this sludge would reduce the overall yield of barium chemicals from the barite concentrate by 5 to 15%.

The rotary kiln process was selected for use in this study as it represents the established technology and insufficient data were available to permit a valid evaluation of the fluidized bed process. A simplified flow plan for the production of barium sulphide from barite ore via the rotary kiln process is presented in Figure 5 and overall operating parameters are provided in Table 21.

The plant is designed to produce 4,400 tonnes per year (as BaS) of black ash for sale, 12,750 tonnes per year (as BaS) of solution for use in the production of BaCO₃ and BaSO₄ and 2,850 tonnes per year (as BaS) of sludge plus BaS solution for use in the production of BaCl₂. Flexibility is included in the design of the black ash leaching circuit to permit the increased production of BaS solution as the demand for derivative chemicals increases.

Barium Carbonate

Barium carbonate is the most important derivative of BaS. It is used widely in the manufacture of glass, brick and porcelain, in the electronics industry and as a raw material in the manufacture of specialty barium chemical products.

Barium carbonate is precipitated from a solution

Table 21
Operating Parameters
Barium Sulphide Production

PLANT CAPACITY:	20,000 t/a BaS	
RAW MATERIALS:	Barite (94% BaSO ₄)	30,000 t/a
	Coal	7,500 t/a
UTILITIES:	Natural Gas	7,000 m ³ /d
	Electricity	120 kW
PRODUCTS:	Black Ash (as BaS), sales	4,400 t/a
	BaS Solution (as BaS), captive use	12,750 t/a
	BaS Sludge (as BaS), captive use	2,850 t/a
OPERATION:		24 h/d
		330 d/y
STAFFING:	Operations, Maintenance and Administration	20

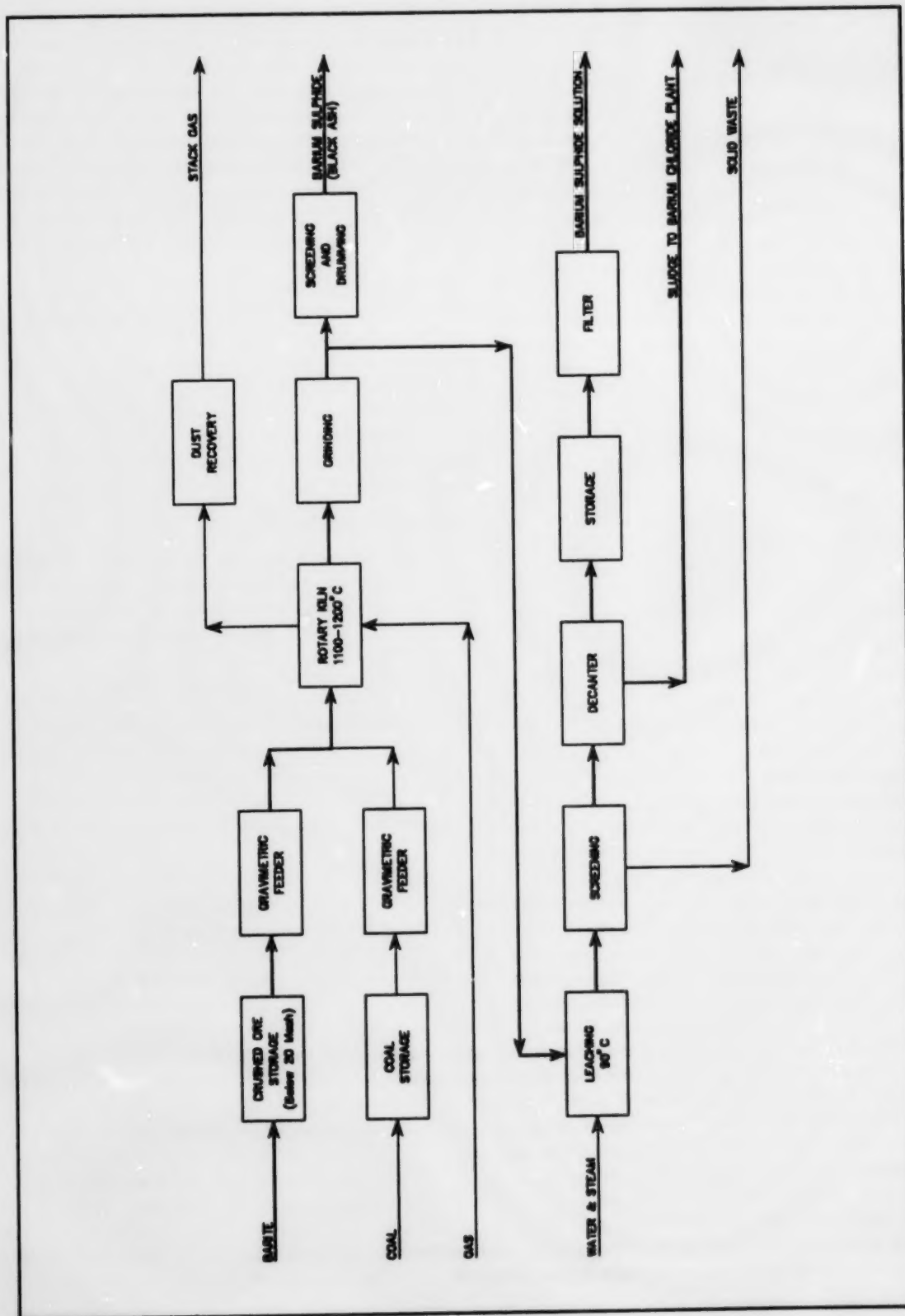
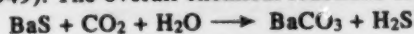


Figure 5. Simplified Flow Plan for Barium Sulphide Production.

of BaS by the addition of CO₂ or Na₂CO₃ (Faith et al. 1975; Kirk et al. 1984; McKetta and Cunningham 1976; Sittig 1968; Ullman and Gerhartz 1985; White 1949). The overall chemical reactions are:



The choice between the two processes depends on the availability and cost of the raw materials, CO₂ and Na₂CO₃, the desired purity and properties of the product BaCO₃ and the desired by-product, H₂S or Na₂S.

Carbon dioxide may be recovered from off-gases exiting the BaS kiln or from the exhaust gases of a boiler or fired heater for use in the production of barium carbonate. The CO₂ is bubbled through the BaS solution to precipitate BaCO₃ and yield by-product H₂S. The BaCO₃ is recovered by filtration, dried and ground to the desired particle size range. Barium carbonate produced by the CO₂ process is a free-flowing powder but typically contains elemental sulphur, BaS and BaSO₄ contaminants.

Hydrogen sulphide, generated as a by-product in the CO₂ process, must be processed further as it cannot be discharged to the atmosphere as H₂S or as SO₂ for environmental and worker safety reasons. It may be converted to elemental sulphur by the Claus process or to Na₂S or (NH₄)₂S by reaction with NaOH or NH₄OH. All of these processes add to the complexity and cost of the production facility but do result in the production of a readily saleable by-product.

In the Na₂CO₃ process, Na₂CO₃ (soda ash) is dissolved in water and reacted with BaS solution to precipitate sulphur-free BaCO₃ and yield by-product Na₂SO₄. The barium carbonate is recovered by filtration or centrifugation, dried and ground to the desired particle size range. Barium carbonate produced by the Na₂CO₃ process contains fewer impurities than material produced by the CO₂ process as it is free of elemental sulphur and contains very little sulphide or sulphate. Typical product purities are given in Table 22.

Barium carbonate produced from Na₂CO₃ tends to cake and is not as free-flowing as material produced via the CO₂ process. This can be overcome, to a great extent, by the proper selection of drying equipment and conditions.

Sodium sulphide is recovered from the reaction solution, after removal of the precipitated BaCO₃, by evaporation and crystallization. The Na₂S product is recovered as Na₂S 3H₂O (60% Na₂S) by conventional centrifugation and drying.

The Na₂CO₃ process was selected for use in this study as Na₂CO₃ is readily available in the province, as a high purity BaCO₃ product is desired and as a potential market exists in the province for by-product

Table 22

Typical Barium Carbonate Purity

BaCO ₃	98.5%, minimum
S	0.02–0.08%
HCl Insolubles	0.1–0.6%

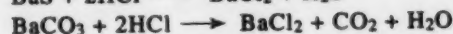
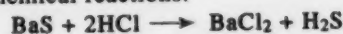
Na₂S as a replacement for Na₂SO₄ in Kraft process pulp and paper mills. Additionally, the Na₂CO₃ process is technically simpler than the CO₂ process and capital costs are comparable, particularly when recovery facilities for by-product H₂S are included.

A simplified flow plan for the production of BaCO₃ from BaS solution and Na₂CO₃ is presented in Figure 6 and overall operating parameters are provided in Table 23. The plant is designed to produce a maximum of 16,000 tonnes per year of BaCO₃ although the normal operating production will be 13,950 tonnes per year, 12,000 tonnes per year for sale and 1,950 tonnes per year for use in the production of BaO/Ba(OH)₂.

Barium Chloride

Barium chloride is used extensively in the electrolytic production of chlorine and sodium hydroxide, magnesium metal and sodium metal, as a flux in the steel industry and nationally in the uranium industry to precipitate radium. It is also used as a raw material in the production of low volume specialty barium chemicals.

Barium chloride is produced by reacting a barium salt, usually BaS or BaCO₃, with HCl (Kirk et al. 1984; McKetta and Cunningham 1976; Ullman and Gerhartz 1985; White 1949), according to the overall chemical reactions:



The selection of the preferable raw material, BaS or BaCO₃, is dependent on their relative availability and cost, the desired purity of the BaCl₂ and disposal costs for the by-product H₂S in the BaS process.

Technical grade BaCl₂ (99% BaCl₂, minimum, or equivalent in the dihydrate form) is typically produced from BaS sludge and BaS solution from a rotary kiln BaS processing plant. The sludge typically contains 5 to 15% of the original barite (BaSO₄) in an acid soluble form. This can be recovered as technical grade BaCl₂ by contacting the sludge with HCl in an agitated reactor and removing Ca, Mg, Al and Si impurities by selective filtration, evaporation and crystallization.

High purity grade BaCl₂ (99.9% BaCl₂, minimum)

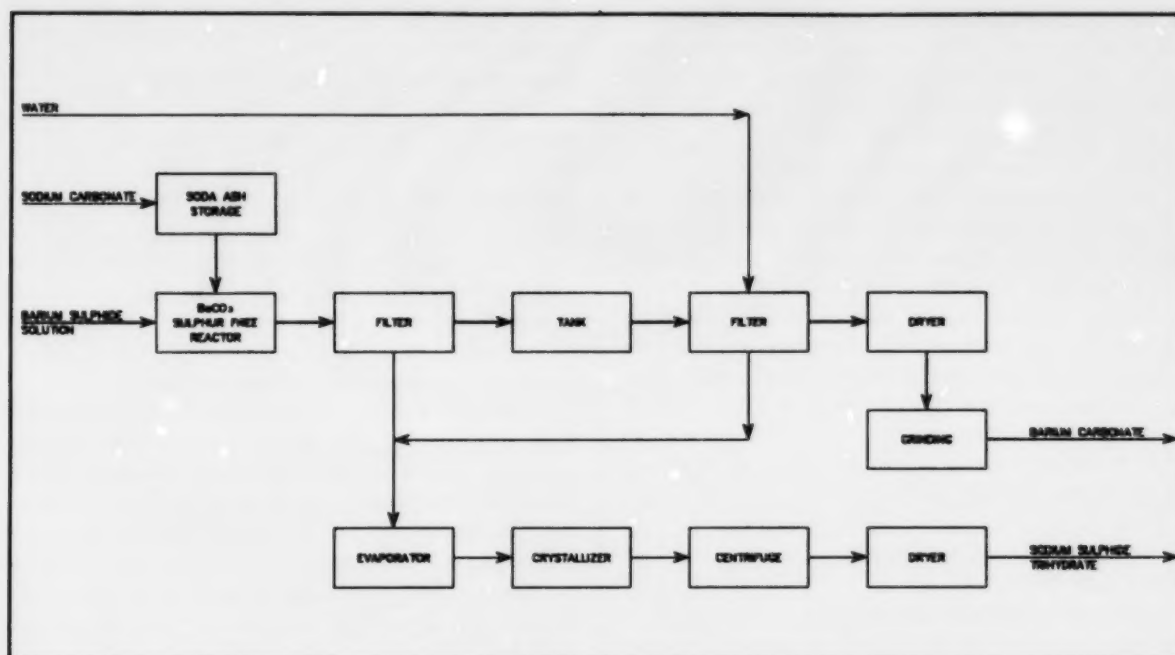


Figure 6. Simplified Flow Plan for Barium Carbonate Production.

is typically produced from BaCO_3 as a higher purity, but more expensive, raw material.

The BaS route to BaCl_2 , making use of the BaS sludge formed in the rotary kiln process for production of the BaS plus additional BaS solution, was selected

for use in this study as its use improves the overall utilization of the barite ore, improves overall economics of the BaS production step and is capable of producing technical grade BaCl_2 . A simplified flow plan for the production of BaCl_2 from BaS sludge and HCl is

Table 23
Operating Parameters
Barium Carbonate Production

PLANT CAPACITY:	16,000 t/a BaCO_3 (13,950 t/a normal operation)	
RAW MATERIALS:	BaS Solution (as BaS)	12,000 t/a
	Na_2CO_3	7,500 t/a
UTILITIES:	Natural Gas	10,000 m^3/d
	Electricity	200 kW
PRODUCTS:	BaCO_3 , sales	12,000 t/a
	BaCO_3 , captive use	1,950 t/a
	Na_2S (as Na_2S), sales	5,500 t/a
OPERATION:		24 h/d
		330 d/a
STAFFING:	Operations, Maintenance and Administration	17

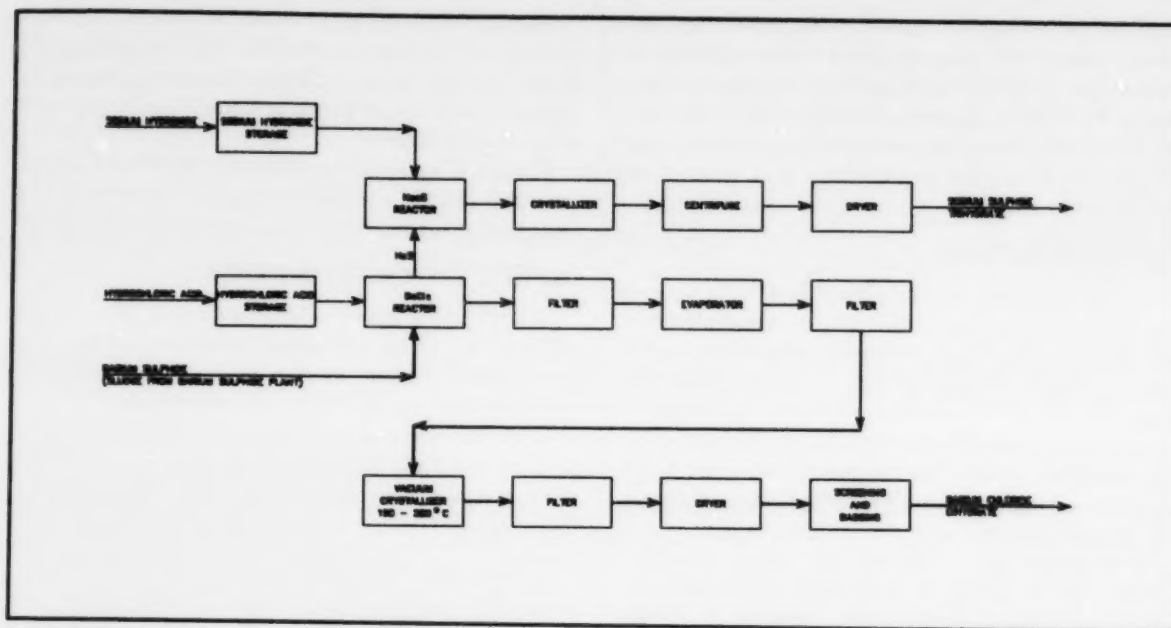


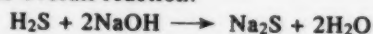
Figure 7. Simplified Flow Plan for Barium Chloride Production.

presented in Figure 7 and overall operating parameters are provided in Table 24.

The BaCl_2 is recovered from solution by vacuum crystallization of $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$, filtration and drying. Anhydrous BaCl_2 can be recovered by high temperature drying or calcination of the dihydrate.

By-product H_2S is contacted with NaOH in an agi-

tated reaction vessel to produce Na_2S , according to the overall reaction:



The Na_2S solution is combined with a similar solution from the BaCO_3 production plant, evaporated and crystallized for recovery of the Na_2S .

Hydrochloric acid and BaCl_2 solutions are very cor-

Table 24
Operating Parameters
Barium Chloride Production

PLANT CAPACITY:	5,000 t/a BaCl_2 (3,500 t/a normal operation)	
RAW MATERIALS:	BaS Sludge (as BaS)	2,850 t/a
	HCl (32%)	3,850 t/a
	NaOH (50%)	2,700 t/a
UTILITIES:	Natural Gas	7,000 m ³ /d
	Electricity	120 kW
PRODUCTS:	BaCl_2 (as BaCl_2), sales	3,500 t/a
	As $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$	4,100 t/a
	Na_2S (as Na_2S), sales	1,300 t/a
OPERATION:		24 h/d 330 d/a
STAFFING:	Operations, Maintenance and Administration	12

rosive to most common materials of construction and special precautions must be taken in the selection of appropriate materials for equipment components and piping. Fibreglass, graphite, hastelloy, titanium, rubber-lined steel or plastic-coated steel vessels and components have been successfully used in these or similar applications.

Barium Sulphate

Synthetic BaSO_4 , or precipitated BaSO_4 , is used in applications in which natural barite is not satisfactory. It is used as a filler and extender in rubber and plastic materials and as a paper coating and filler. Important properties are its insolubility in water and organic binders, its high degree of whiteness, its fine grain size and a low iron content. Special photographic and X-ray applications require ultra-high purity BaSO_4 with less than 10 ppm iron and very low sulphur content.

Precipitated BaSO_4 , or blanc fixe, for use as a filler and extender is usually manufactured from BaS solution by the addition of Na_2SO_4 (Kirk et al. 1984; McKetta and Cunningham 1976; Ullman and Gerhartz 1985), as per the overall reaction:



Special high purity grades of BaSO_4 are typically produced from BaCO_3 or BaCl_2 by the addition of Na_2SO_4 or H_2SO_4 .

The production of precipitated BaSO_4 from BaS solution via the Na_2SO_4 route was selected for this study as this grade of product, blanc fixe, represents the greatest share of the potential market, as Na_2SO_4 is readily available and as Na_2S recovery facilities are included in the BaCO_3 processing plant. A simplified flow plan for the production of BaSO_4 from BaS solution and Na_2SO_4 is presented in Figure 8 and overall operating parameters are provided in Table 25.

Barium sulphate is produced by contacting BaS solution with high purity Na_2SO_4 solution in an appropriate reaction vessel. The BaSO_4 is recovered by filtration, drying, sintering and grinding to give the desired grain size.

The Na_2S solution is combined with other solution from the BaCO_3 and BaCl_2 plants, evaporated and crystallized for recovery of the Na_2S .

Barium Oxide/Hydroxide

Barium oxide and hydroxide are used mainly in the manufacture of oil and grease additives, as the raw material for organic barium salts and for dehydration/deacidification of fats, oils and waxes.

Barium oxide is produced primarily by the decomposition of BaCO_3 in the presence of a source of carbon at high temperature (Kirk et al. 1984; McKetta and Cunningham 1976; Sittig 1968). The overall reaction is:



The use of carbon in the process significantly lowers the temperature at which the BaCO_3 decomposes; it also serves as a source of energy for the high temperature process.

The decomposition reaction can be carried out in a rotary kiln or in a fluidized bed. In the rotary kiln process, coal, coke or carbon black is used as the source of carbon. As a result, the level of impurities in the carbon source must be carefully controlled to avoid contamination of the BaO product. Most modern plants use the fluidized bed process as natural gas can be used as the source of carbon. This results in the production of high purity BaO with typical purity as shown in Table 26.

The fluidized bed process was selected for use in this study as it represents state-of-the-art technology

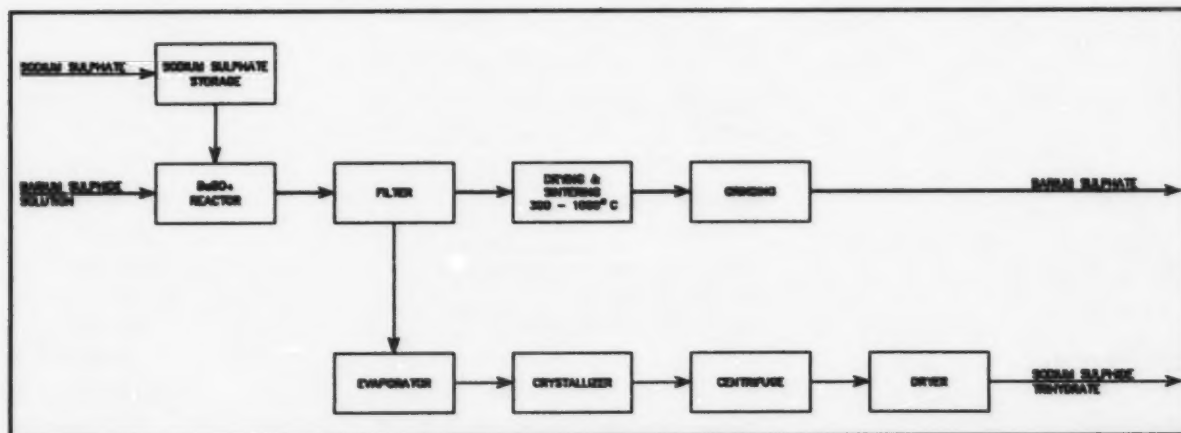


Figure 8. Simplified Flow Plan for Barium Sulphate Production.

Table 25
Operating Parameters
Barium Sulphate Production

PLANT CAPACITY:	1,500 t/a BaSO ₄ (1,000 t/a normal operation)	
RAW MATERIALS:	BaS Solution (as BaS) Na ₂ SO ₄	750 t/a 610 t/a
UTILITIES:	Natural Gas Electricity	2,000 m ³ /d 100 kW
PRODUCTS:	BaSO ₄ , sales Na ₂ S (as Na ₂ S), sales	1,000 t/a 330 t/a
OPERATION:		24 h/d 330 d/a
STAFFING:	Operations, Maintenance and Administration	5

and produces a high grade, highly reactive product. A simplified flow plan for the fluidized bed process is presented in Figure 9 and overall operating parameters are provided in Table 27.

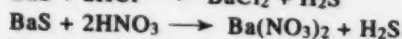
In the fluidized bed process, BaCO₃ is contacted with natural gas in the reaction zone at 1000 to 1250°C. The BaCO₃ decomposes, yielding BaO. The BaO is cooled, ground and packaged for sale. Handling and storage of BaO must be carried out with extreme caution and under controlled conditions as the oxide will react with CO₂ and water in the atmosphere to form BaCO₃ or Ba(OH)₂ in a very exothermic reaction.

Much of the BaO produced is converted to more stable Ba(OH)₂ products, either the monohydrate or the octahydrate form. Barium hydroxide octahydrate is prepared by adding water to BaO in an appropriate reaction vessel with suitable heat removal capability. The octahydrate product is cooled, flaked and packaged. Barium hydroxide monohydrate is produced by drying the octahydrate reaction mass in heated vacuum or rotary drum dryers.

Multi-Purpose Plant Possibilities

The production of barium chemicals from barite or BaS is characterized by reaction between BaS and a

number of inorganic salts or acids to produce the barium salts, as illustrated below:



Many of the reaction systems, product characteristics and by-product handling requirements are similar, leading to the possibility of constructing a multi-purpose plant with the capability of producing multiple products in a single production train.

Based on an analysis of the processing steps required to produce the selected barium chemicals, BaS, BaCO₃, BaCl₂, BaSO₄, BaO and Ba(OH)₂, it appears that the only products that can be produced in a single production train, in blocked operation, are BaCO₃ and BaSO₄. Production of both barium chemicals involves the reaction of BaS solution with the corresponding sodium salt, Na₂CO₃ or Na₂SO₄, resulting in the precipitation of the barium salt and the co-production of by-product Na₂S.

The barium salt is recovered by filtration or centrifugation, and drying. The Na₂S is recovered by evaporation of the solution, crystallization of the Na₂S in the trihydrate form, centrifugation and drying.

The processing steps required for the production of BaS from barite ore include a high temperature rotary kiln step for the reduction of barite, grinding of the crude BaS or black ash and leaching of soluble BaS from the black ash in a multi-stage leach circuit. These processing steps are different than those used in the production of any of the barium chemicals, with the possible exception of BaO, thereby minimizing the

Table 26
Purity of Barium Oxide

BaO	97-99%
BaCO ₃	1-3%
BaO ₂ (peroxide)	1%, maximum

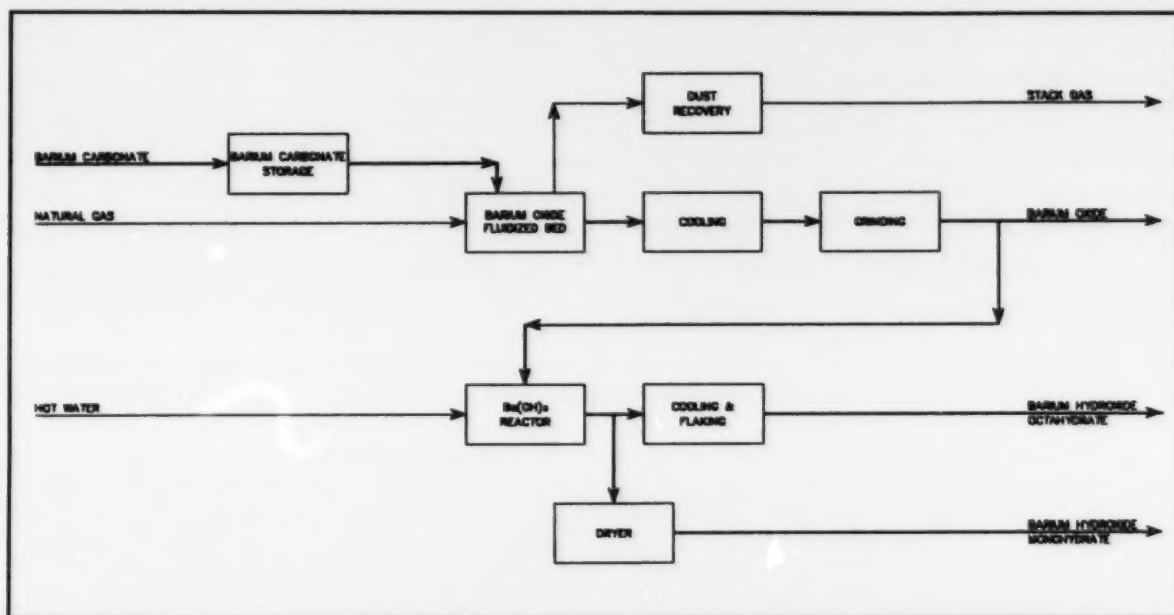


Figure 9. Simplified Flow Plant for Barium Oxide and Barium Hydroxide Production.

possibility of their use in producing multiple products.

Production of BaCl_2 from BaS and HCl involves the production of a soluble BaCl_2 and by-product H_2S . Recovery of the BaCl_2 from solution involves evaporation, filtration, vacuum crystallization, product filtration and drying. These processing steps are different than those used in the production of the other barium chemicals. In addition, HCl and BaCl_2 are extremely corrosive, requiring special materials of

construction for all equipment and piping in contact with them. Finally, conversion of the by-product H_2S to saleable Na_2S requires an additional conversion step, reaction with NaOH . All of these factors minimize the potential for the production of multiple products which include BaCl_2 in a single plant.

Barium oxide is produced in a high temperature rotary kiln or fluidized bed reactor by the reduction of BaCO_3 in the presence of carbon. While the process-

Table 27
Operating Parameters
Barium/Hydroxide Production

PLANT CAPACITY:	3,000 t/a BaO (1,500 t/a normal operation)	
RAW MATERIALS:	Barium Carbonate	1,950 t/a
UTILITIES:	Natural Gas	800 m ³ /d
	Electricity	120 kW
PRODUCTS:	Barium Oxide	500 t/a
	Barium Hydroxide Octahydrate	1,030 t/a
	Barium Hydroxide Monohydrate	620 t/a
OPERATION:		24 h/d 330 d/a
STAFFING:	Operations, Maintenance and Administration	12

ing steps appear to be similar to those used in the production of BaS (black ash), the production of both products in a single rotary kiln plant was not considered practical because of the concern of contamination of the BaO with residual BaS or barite ore. If the fluidized bed process for the production of BaS from barite ore and natural gas can be shown to be commercially demonstrated and competitive, the co-production of BaS and BaO in a common plant might be possible as contamination concerns would be minimized.

Even though the potential for the production of multiple barium chemicals in a single process unit was found to be limited and only applicable to barium carbonate and barium sulphate, a production complex capable of producing BaS, BaCO₃/BaSO₄, BaCl₂ and BaO/Ba(OH)₂ would have a great deal of flexibility for the production of other specialty chemicals to meet low volume, value-added opportunities:

- the production of Ba(NO₃)₂ from BaSO₄ and HNO₃
- the production of high purity BaCl₂, BaSO₄ or Ba(NO₃)₂ from BaCO₃ and the appropriate sodium salt or inorganic acid
- the production of lithopone, a white pigment containing BaSO₄ and ZnS, from BaS solution and ZnSO₄
- the production of barium peroxide by the controlled heating of BaO in an air/oxygen atmosphere.

Production Costs

The production costs for the barium chemicals under consideration are dependent on the capital cost of the facilities, the cost of raw materials, the plant operating costs, the financial parameters assumed for recovery of invested capital, product marketing costs and the capacity of the production facilities.

Preliminary capital cost estimates were prepared for each production facility discussed in the previous section of this report, as presented in Table 28.

The capital costs are considered preliminary estimates as they were factored from budget prices for individual items of process equipment using established estimating procedures. The proposed barium chemicals facility is a stand-alone, grass-roots facility with raw materials unloading and storage facilities, process facilities to produce the listed chemicals in dedicated process units, product storage, packaging and loadout systems and all offsite/utility systems needed to operate the facility. A single evaporation/crystallization unit is provided to recover by-product sodium sulphate from the BaCO₃, BaCl₂ and BaSO₄ operations. The costs of all common facilities have been apportioned to the individual production units on the basis of the requirements of each unit so that production costs could be determined for the individual barium chemicals.

Preliminary information on the sizes or design capacities of major items of equipment and typical purchase costs are provided in Appendix B.

Preliminary production cost estimates were determined for each of the barium chemicals under consideration, as summarized in Table 29A.

The production cost of each chemical includes the cost of raw materials, the cost of plant utilities, operating and maintenance costs, local taxes and insurance, a capital recovery charge of 20% per year of initial capital cost less by-product credits where applicable.

The above production costs are based on a cost of barite, delivered to the chemicals plant, of \$108 per tonne. This is considered to be optimistic as the entire 30,000 tonnes per year of barite would have to be produced in a single barite production plant in the Thunder Bay area. Established barite reserves in the area may not be adequate to provide sufficient ore for the production of 30,000 tonnes per year of high quality barite

Table 28

Estimated Capital Cost for Different Barium Chemical Production Units

Chemical Production Unit	Plant Capacity t/a	Estimated Capital Cost,\$million
BaS	20,000	11
BaCO ₃	16,000	7
BaCl ₂	5,000	4.8
BaSO ₄	1,500	1.6
BaO	3,000	4.6
TOTAL FACILITY		29

Table 29A
Preliminary Production Costs for Different Barium Chemicals

Chemical	Normal Production t/a	Production Cost, \$/t	Reported Market Value\$/t
BaS	4,400	413 sales	N/A
	15,600	388 captive	
BaCO ₃	12,000	592 sales	550-800
	1,950	567 captive	
BaCl ₂	3,500	1,098 sales	500-840
BaSO ₄			
- dedicated plant	1,000	1,085 sales	800
- multi-product	1,000	815 sales	800
plant			
BaO	500	1,890 sales	N/A
Ba(OH) ₂			
- Monohydrate	620	1,535 sales	1100-1250
- Octahydrate	1,030	920 sales	N/A

(94% BaSO₄, minimum). The barium chemicals plant would be located in Thunder Bay in this case to minimize shipping costs for the barite.

A more realistic case to consider is the use of barite recovered from Hemlo gold mill tailings or barite minerals produced at two 15,000 tonnes per year production plants, one in the Thunder Bay area and one in the Matachewan area, for the production of the barium chemicals. The barium chemicals plant, in this case, would be centrally located to be closer to the barium chemicals market, thereby necessitating shipment of the barite from the production plants to the chemicals plant. The estimated production and shipping cost for barite is in the range of \$180 to \$210 per tonne. With this higher cost feedstock, the production cost of the barium chemicals increases proportionally, illustrated in Table 29B.

All new equipment was assumed in preparing capital cost estimates for the barium chemicals facility. For certain items of equipment, in particular the rotary kiln in the BaS plant, product filters, centrifuges, dryers and grinding mills, the potential exists for utilizing used, reconditioned equipment, thereby reducing the capital cost of the production facilities. Selective use of reconditioned equipment throughout the chemicals facility would reduce the overall capital cost by only 5 to 10% as direct equipment costs only contribute 25 to 30% of the total cost of a typical chemicals project.

A reduction in capital cost of this magnitude would not dramatically affect the production cost of the barium chemicals as capital-related costs only make up a portion of the estimated production costs. Indicated production costs would only be reduced 2 to 3% as a result of the selective use of reconditioned equipment.

Table 29B
Production Costs for Barium Chemicals Using Higher Cost Feed Stock

Chemical	Plant Gate Production Cost, \$/t	
	Barite @ \$108/t	Barite @ \$180-210/t
BaS (captive)	388	495-540
BaCO ₃ (sales)	592	685-725
BaCl ₂	1,098	1,185-1,220
BaSO ₄		
- dedicated plant	1,085	1,165-1,200
- multi-product plant	815	895-930
BaO	1,890	2,010-2,060
Ba(OH) ₂		
- Monohydrate	1,535	1,635-1,675
- Octahydrate	920	980-1,000

Basis for Capital and Production Cost Estimates

Preliminary capital cost estimates were developed for each barium chemical production unit (BaS , BaCO_3 , BaCl_2 , BaSO_4 and BaO/Ba(OH)_2), as part of a grass-roots barium chemicals production complex. Each barium chemical is produced in a dedicated production unit with dedicated raw materials storage and product storage facilities. Common support facilities are provided for the chemicals complex. These include raw materials unloading systems, product packaging and loadout systems, offsite and utility systems needed to operate the facility and effluent treatment/environmental control systems. In addition, a single evaporation/crystallization unit is provided to recover by-product Na_2S for sale from the BaCO_3 , BaCl_2 and BaSO_4 operations.

The cost of all common facilities have been apportioned to the individual production units on the basis of the requirements of each unit so that production costs can be determined for the individual barium chemicals.

The estimated capital costs were based on budget prices for major items of process equipment plus factors for installation, piping, instrumentation, electrics, structural steel and concrete, site services, process buildings, engineering and construction, spare parts and startup allowances and overall project contingencies, using established estimating procedures. No allowances were included for land acquisition, for major warehousing of raw materials or final products or for environmental assessment costs.

The production cost estimate for each barium chemical includes the cost of raw materials, the cost of plant utilities (natural gas, electricity, water), operating and maintenance costs (labour, replacement parts, supplies), local taxes and insurance, a capital recovery charge of 20% per year of initial capital cost, less by-product credits where applicable. Table 30 shows the main cost parameters used in determining the production cost for each barium chemical.

A capital recovery factor of 20% per year was selected as it represents the minimum return on capi-

Table 30
Main Cost Parameters Used in Determining Production for Barium Chemicals

RAW MATERIALS	
Barite	\$108/t, base price, single mill (\$180-210/t from alternate sources, Hemlo or two smaller processing mills)
Na_2CO_3	\$225/t
Na_2SO_4	\$150/t
HCl (32%)	\$175/t
NaOH (50%)	\$150/t
Coal (low sulphur)	\$ 80/t
UTILITIES	
Natural Gas	\$120/103m ³
Electricity	\$0.05/kWh
Treated Water	\$0.50/m ³
Operations and Administration Staff	Manpower count for each plant, \$40,000/annum average
Maintenance Parts and Labour	4% of capital cost/yr
Taxes and Insurance	1% of capital cost/yr
Operating Supplies	10% nominal of the cost of utilities, labour and maintenance
Capital Recovery Charge	20% of capital cost/yr
By-Product Credit	\$250/t to be marketed primarily to pulp and paper companies as a replacement for sodium sulphate in Kraft mills.
Marketing Cost	An allowance of \$25/t of net saleable product.

Table 31
Production Cost Summary
Barium Sulphide

PLANT CAPACITY:	20,000 tonnes per year BaS	
CAPITAL COST:	\$11,000,000	
PRODUCTION COST	ANNUAL COST,	UNIT COST,
	\$	\$/t BaS
Raw Materials- Barite	3,240,000.	162.00
- Coal	600,000.	30.00
Utilities- Natural Gas	277,000.	13.85
- Electricity	48,000.	2.40
- Water	66,000.	3.30
Operations and Administration Staff	640,000.	32.00
Maintenance Labour and Parts	442,000.	22.10
Taxes and Insurance	110,000.	5.50
Operating Supplies	137,000.	6.85
Capital Recovery	2,200,000.	110.00
Total Production Cost	7,760,000.	388.00
Marketing Cost (for net sales)		25.00
Plant Gate Price		413.00

tal expected by a private investor. A capital recovery factor of 20%, or a simple payback of 5.0 years, equates approximately to an after-tax discounted cash flow return on investment of 15%, in constant dollars.

The estimated production costs do not include product shipping costs to potential customers, dealer markups or the impact of the Goods and Services Tax.

Market prices for barium chemicals discussed in this section of the report, as an indication of the economic potential for the production of individual materials, were taken from the Law, Sigurdson & Associates and SRI International report (1989).

Barium Sulphide

The estimated capital cost of the BaS plant, with a production capacity of 20,000 tonnes per year of BaS (as BaS), is \$11 million. The estimated production cost of BaS, with a base barite price of \$108 per tonne, is \$388 per tonne for captive use material and \$413 per tonne for net sales product, as presented in Table 31.

In order to realize the \$108 per tonne production and delivery cost for barite, a single mineral processing mill with a capacity of 30,000 tonnes per year of high quality barite would be required. Both the processing mill and the chemicals production facility would have to be located in the Thunder Bay area, close to estab-

lished mineral deposits, to minimize barite transportation costs.

Processing of higher cost barite, such as barite recovered from Hemlo area gold mill tailings or barite produced in two smaller processing mills (15,000 tonnes per year mills at Thunder Bay and Matachewan) and shipped to a central chemicals facility, would result in higher cost barium sulphite, as shown in Table 32.

Although market values are not reported regularly for BaS, primarily as the bulk of the material is for captive use, it is believed that the indicated production cost of \$388 to 413 per tonne (with \$108 per tonne barite) is competitive with current supplies. The major consideration, however, is the impact of this BaS cost

Table 32
Barium Sulphide Production Cost

Barite @ \$108/t	\$388/t captive use \$413/t sales
Barite @ \$180-210/t	\$495-540/t captive use \$520-565/t sales

Table 33
Production Cost Summary
Barium Carbonate

PLANT CAPACITY:	16,000 t/a BaCO ₃ (13,950 t/a normal operation)	
CAPITAL COST:	\$7,000,000	
PRODUCTION COST	ANNUAL COST,	UNIT COST,
	\$	\$/t BaCO₃
Raw Materials- BaS Solution	4,656,000.	333.76
- Sodium Carbonate	1,688,000.	121.00
Utilities- Natural Gas	396,000.	28.38
- Electricity	79,000.	5.66
- Water	20,000.	1.43
Operations and Administration Staff	560,000.	40.14
Maintenance Labour and Parts	281,000.	20.14
Taxes and Insurance	70,000.	5.02
Operating Supplies	135,000.	9.68
Capital Recovery	1,400,000.	100.36
Total Production Cost	9,285,000.	665.57
By-Product Na ₂ S Credit	(1,375,000.)	(98.57)
Net Production Cost	7,910,000.	567.00
Marketing cost (for net sales)		25.00
Plant Gate Price		592.00

on the production cost of the other barium chemicals as BaS is the precursor of these materials. Net sales of BaS are assumed to be only 4,400 tonnes per year; this quantity would probably be reduced as the demand for other value-added barium chemicals increases.

Barium Carbonate

The estimated capital cost for the BaCO₃ plant, with a production capacity of 16,000 tonnes per year of BaCO₃, is \$7 million. The estimated production cost of BaCO₃ is \$567 per tonne for captive use material and \$592 per tonne for net sales product, relative to the base barite price of \$108 per tonne, as presented in Table 33. This price increases substantially as the price of barite ore increases to the range of \$180 to 210 per tonne, as shown in Table 34.

Normal operating capacity in the BaCO₃ plant is assumed to be 13,950 tonnes per year of BaCO₃, 12,000 tonnes per year for sales and 1,950 tonnes per year for captive use in the production of BaO and Ba(OH)₂.

Market values for BaCO₃ are reported to be in the

range of \$550 to \$800 Cdn per tonne for high grade material supplied in Canada and the North-Eastern United States, with Chinese material costing \$550 to \$600 per tonne and European product costing \$800 per tonne. U.S. quoted list prices are in the range of \$740 Cdn per tonne, FOB plant in Georgia.

Based on this information, there appears to be an economic potential for the production of BaCO₃ and the precursor BaS in Ontario for marketing in Canada and the North-Eastern United States provided that competitive barite ore prices (below about \$120 to

Table 34
Barium Carbonate Production Cost

Barite @ \$108/t (BaS @ \$388/t)	\$567/t captive use \$592/t sales
Barite @ \$180-210/t (BaS @ \$495-540/t)	\$660-700/t captive use \$685-725/t sales

Table 35
Production Cost Summary
Barium Chloride

PLANT CAPACITY:	5,000 T/A BaCl ₂ (3,500 t/a normal operation)	
CAPITAL COST:	\$4,800,000	
PRODUCTION COST	ANNUAL COST,	UNIT COST,
	\$	\$/t BaCl₂
Raw Materials- BaS Sludge	1,106,000.	316.00
- Hydrochloric Acid	674,000.	192.57
- Sodium Hydroxide	405,000.	115.72
Utilities- Natural Gas	158,000.	45.14
- Electricity	48,000.	13.72
- Water	5,000.	1.43
Operations and Administration Staff	400,000.	114.29
Maintenance Labour and Parts	192,000.	54.86
Taxes and Insurance	48,000.	13.72
Operating Supplies	84,500.	24.13
Capital Recovery	960,000.	274.27
Total Production Cost	4,080,500.	1,165.85
By-Product Na ₂ S Credit	(325,000.)	(92.85)
Net Production Cost	3,755,000.	1,073.00
Marketing Cost		25.00
Plant Gate Price		
- as Barium Chloride		1,098.00
- as Barium Chloride Dihydrate		937.00

\$150 per tonne), delivered to the chemicals plant, can be realized. A production facility capable of producing 15,000 to 20,000 tonnes per year of barium sulphide (6,000 to 8,000 tonnes per year net sales) and 10,000 to 15,000 tonnes per year of barium carbonate is considered to be an economic size. Unit production costs increase rapidly in smaller sized plants as capital recovery charges and fixed operating costs remain relatively constant, representing an ever increasing portion of the unit production cost as plant production rate is reduced.

Barium Chloride

The estimated capital cost for the BaCl₂ plant, with a production capacity of 5,000 tonnes per year of BaCl₂, is \$4.8 million. The estimated production cost for BaCl₂, for a normal operating capacity of 3,500 tonnes per year, is presented in Table 35. An overall production cost (or plant gate price) of \$1,098 per tonne for anhydrous barium chloride or \$937 per tonne for BaCl₂·2H₂O is indicated, relative to the base barite price of \$108 per tonne. These prices increase moderately as the price of barite increases to the range of \$180 to \$210 per tonne, as presented in Table 36.

Table 36
Barium Chloride Production Cost

	Anhydrous	Dihydrate
Barite @ \$108/t (BaS @ \$388/t)	\$1,098/t	\$937/t
Barite @ \$180-210/t (BaS @ \$495-540/t)	\$1,185-1,220/t	\$1,010-1,045/t

Market values for anhydrous BaCl_2 are reported to be in the range of \$500 to \$840 Cdn per tonne, based largely on product purity. Quoted prices for U.S. and European material, which are high quality product, are at the upper end of this price range, that is, \$800 to \$840 per tonne.

Even if \$800 to \$840 per tonne can be realized for BaCl_2 produced in an Ontario based chemical facility, it does not appear that its production has any immediate economic potential. Indicated production costs are in the range of \$1,100 per tonne (anhydrous basis) even with optimistically priced barite ore.

Barium Sulphate

The estimated capital cost of a dedicated BaSO_4 plant, with a production capacity of 1,500 tonnes per year of barium sulphate, is \$1.6 million. The estimated production cost for barium sulphate in a dedicated plant, for a normal operating capacity of 1,000 tonnes per year, is presented in Table 37. A plant gate production price of \$1,085 per tonne is estimated, relative to the base barite price of \$108 per tonne. This price

increases moderately with increased barite prices.

As an option, the co-production of BaCO_3 and BaSO_4 in a single production unit (multi-product plant) was considered as a means of reducing the production cost of the BaSO_4 . This type of operation appears to be feasible as the processing steps for the production of BaCO_3 and BaSO_4 are similar, with the main difference being in the use of Na_2CO_3 as raw material for the production of BaCO_3 and Na_2SO_4 for BaSO_4 . The estimated capital cost of the $\text{BaCO}_3/\text{BaSO}_4$ plant, with a combined capacity of 16,000 tonnes per year BaCO_3 and 1,500 tonnes per year BaSO_4 , is \$8.4 million. The estimated production costs for the BaCO_3 and BaSO_4 , for normal operating capacities of 13,950 tonnes per year BaCO_3 and 1,000 tonnes per year BaSO_4 , are presented in Table 38. By keeping the production cost for BaCO_3 the same as in the dedicated plant situation, a plant gate production price for BaSO_4 of \$815 per tonne is indicated.

This is significantly lower than in the dedicated plant case as substantial operating cost savings are realized.

Table 37
Production Cost Summary
Barium Sulphate

PLANT CAPACITY:	1,500 T/A BaSO_4 (1,000 t/a normal operation)	
CAPITAL COST:	\$1,600,000	
PRODUCTION COST	ANNUAL COST, \$	UNIT COST, \$/t BaSO_4
Raw Materials- BaS Solution	291,000	291.00
- Sodium Sulphate	92,000	92.00
Utilities- Natural Gas	79,000	79.00
- Electricity	40,000	40.00
- Water	3,000	3.00
Operations and Administration Staff	200,000	200.00
Maintenance Labour and Parts	62,000	62.00
Taxes and Insurance	16,000	16.00
Operating Supplies	39,000	39.00
Capital Recovery	320,000	320.00
Total Production Cost	1,142,000	1,142.00
By-Product Na_2S Credit	(82,000)	(82.00)
Net Production Cost	1,060,000	1,060.00
Marketing Cost		25.00
Plant Gate Price		1,085.00

Table 38
Production Cost Summary
Barium Carbonate and Sulphate in Single Plant

PLANT CAPACITY:	16,000 t/a BaCO ₃ + 1,500 t/a BaSO ₄ (13,950 t/a and 1,000 t/a normal operation)	
CAPITAL COST:	\$8,400,000	
PRODUCTION COST	ANNUAL COST, BaCO₃ \$	ANNUAL COST, BaSO₄ \$
Raw Materials- BaS Solution	4,656,000	291,000
- Sodium Carbonate	1,688,000	-
- Sodium Sulphate	-	92,000
Utilities- Natural Gas	396,000	79,000
- Electricity	79,000	40,000
- Water	20,000	3,000
Operations & Administration Staff	560,000	-
Maintenance Labour and Parts	281,000	55,000
Taxes and Insurance	70,000	14,000
Operating Supplies	135,000	18,000
Capital Recovery	1,400,000	280,000
Total Production Cost	9,285,000	872,000
By-Product Na ₂ S Credit	(1,375,000)	(82,000)
Net Production Cost	7,910,000	790,000
Net Production Cost, \$/t	567.00	790.00
Marketing Cost (net sales), \$/t	25.00	25.00
Plant Gate Price, \$/t	592.00	815.00

Table 39 is a summary of barium sulphate production costs (plant gate price) as a function of barite price.

Market values for BaSO₄ are reported to be in the range of \$800 Cdn per tonne for synthetic, pigment and filler grade material. Based on this information, it does not appear that there is any significant economic potential for the production of BaSO₄ in an

Ontario-based chemical facility even with optimistically priced barite ore. However, production of BaSO₄ in a multi-product BaCO₃ plant might be considered to meet short term demands for high quality, value added product.

Table 39
Barium Sulphate Production Cost

	Dedicated Plant	Multi-Purpose Plant
Barite @ \$108/t (BaS @ \$388/t)	\$1,085/t	\$815/t
Barite @ \$180-210/t (BaS @ \$495-540/t)	\$1,165-1,200/t	\$895-930/t

Table 40
Production Cost Summary
Barium Oxide/Hydroxide

PLANT CAPACITY:	3,000 t/a BaO (1,500 t/a normal operation)	
CAPITAL COST:	\$4,600,000	
PRODUCTION COST	ANNUAL COST, \$	UNIT COST, \$/t BaO
Raw Materials- Barium Carbonate	1,105,500.	737.00
Utilities- Natural Gas	32,000.	21.33
- Electricity	48,000	32.00
- Water	3,000.	2.00
Operations and Administration Staff	400,000.	266.67
Maintenance Labour and Parts	183,000.	122.00
Taxes and Insurance	46,000.	30.67
Operating Supplies	60,000.	40.00
Capital Recovery	920,000.	613.33
Total Production Cost	2,797,500.	1,865.00
Marketing Cost		25.00
Plant Gate Price		
- as Barium Oxide		1,890.00
- as Barium Hydroxide Monohydrate		1,535.00
- as Barium Hydroxide Octahydrate		920.00

Barium Oxide/Hydroxide

The estimated capital cost for a BaO/Ba(OH)₂ plant, with a production capacity of 3,000 tonnes per year of BaO equivalent (BaO plus Ba(OH)₂), is \$4.6 million. The estimated production costs for barium oxide and hydroxides, for a normal operating capacity of 1,500 tonnes per year barium oxide equivalent, are presented in Table 40. Plant gate production prices of \$1,890 per tonne for BaO, \$1,535 per tonne for Ba(OH)₂·H₂O and \$920 per tonne for Ba(OH)₂·8H₂O are indicated. These prices increase moderately with increased barite prices, as shown in Table 41.

Market values for Ba(OH)₂·H₂O, the highest volume chemical of the BaO/Ba(OH)₂ family of chemicals, are reported to be in the range of \$1,100 to \$1,200 per tonne for high quality material. As the product cannot be produced economically at this price in an Ontario based chemicals facility, even with optimistically priced barite, there does not appear to be any significant economic potential for its production.

Table 41
Barium Oxide Production Cost

Barite @ \$108/t (BaCO ₃ @ \$567/t)	\$1,890/t
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Barite @ \$180-210/t (BaCO ₃ @ \$660-700/t)	\$2,010-2,060/t
---	-----------------

Barium Hydroxide Production Cost

	Monohydrate	Octahydrate
Barite @ \$108/t (BaCO ₃ @ \$567/t)	\$1,535/t	\$920/t
Barite @ \$180-210/t (BaCO ₃ @ \$660-700/t)	\$1,635-1,675/t	\$980-1,000/t

5. Options for Fluorspar Production

Production Options

The North American market for fluorspar includes the metallurgical and acid grade material. Major producers in Canada, the United States and Mexico have a combined production capacity of approximately 1.4 million tonnes, reported for 1987 (Prud'homme 1989). Metallurgical grade material, generally above 60% CaF_2 content, is supplied to steel mills. Acid grade material, with a minimum of 97% CaF_2 content, is used mainly for HF production and alumina refining.

Total imports to Canada amounted to 194,000 tonnes (all material) in 1988, of which about 70% is reported to be acid grade material (Law, Sigurdson and Associates and SRI International 1989). Most of this is obtained from Mexico although the recently commissioned plant of St. Lawrence Fluorspar in Newfoundland has a capacity of 80,000 tonnes per year. A major consumer in Ontario is the Allied Signal plant in Amherstburg.

Prud'homme 1989 has noted that the stringent specifications for acid grade material have created a slight price increase, and that "Producers of high grade filtercake are in a better position to absorb any fluctuations in demand."

Considering the nature of known fluorspar deposits in Ontario and the volume of imported material, the most favourable production option in Ontario appears to be for acid grade material. Low shipping costs to an Ontario based consumer should outweigh the probably lower production costs of the major suppliers of imported material.

The known resources in Ontario preclude consideration of a large production facility. Based on typical grades of deposits and dispersion of the vein structures, a production rate of 15,000 tonnes per year is considered reasonable for initial operation of a centralized processing plant. This would entail mining of up to 50,000 tonnes per year of material containing an average of 50% CaF_2 . A favourable location would be in South-Eastern Ontario near the town of Madoc.

Such a plant would be designed to produce acid-grade fluorspar. Depending on the nature of material mined, barite might also be produced as a by-product.

Studies by CANMET with samples of fluorspar from many Canadian locations showed a difficulty in upgrading to acid-grade material (Collings and Andrews 1988b). Gravity separation methods produced concentrates often below 90% CaF_2 due to the difficulty in separating fluorspar from other minerals having similar characteristics. Flotation tests illustrated the potential of the method for producing the required grade of concentrate. Barite was removed by

flotation prior to fluorspar recovery from samples containing both minerals.

A processing plant designed to treat a variety of ores, as mined from several veins, is proposed as a centrally located facility. Processes selected to achieve the maximum possible upgrading, by removal of contaminants, are included.

In the proposed mill, fluorspar is crushed and reduced by hammer mill prior to initial recovery by jigs and tables. A high grade gravity concentrate may be produced if the mineralogy of the ore is suitable. Rejects from the gravity circuit are ground to less than 300 μm prior to removal of metal sulphides (pyrite and others) and barite in flotation circuits. A final flotation stage will recover a fluorspar concentrate. Further upgrading of the concentrate will be achieved by high intensity magnetic separation. The concentrate will be filtered and dried for shipment. The flowsheet is illustrated in Figure 10.

Specifications

Acid Grade Fluorspar

The specifications for acid grade fluorspar are set by the consumers and are based on level of contaminants and size analysis. A typical specification is illustrated in Table 42.

Material meeting these specifications is generally produced by plants employing flotation, but not all sources can satisfy the restrictions which may be imposed on minor levels of contaminants including lead, phosphorus and arsenic.

Metallurgical Grade Fluorspar

The specifications for fluorspar sold as metallurgical grade material vary according to the demands of the particular consumers, mainly steel plants. Generally a minimum level for (CaF_2) content is 60%, and size analysis is specified. Reported specifications for three Ontario steel plants (Collings and Andrews 1988b) indicate a higher required level of CaF_2 between 75 and 80%. Specifications for contaminants by these consumers range as shown in Table 43.

Effective CaF_2 equals Total CaF_2 minus 2.5 times silica content (McKetta and Cunningham 1976).

Table 42
Typical Specification for Acid Grade Fluorspar

Calcium fluoride	97%	minimum
Silica	1%	maximum
Calcium carbonate	1.25%	maximum
Sulphur	0.03%	maximum
Heavy metal oxides	0.4%	maximum
Particle size	150	μm *

*References Collings and Andrews 1988b; Law, Sigurdson and Associates SRI International 1989.

Table 43
Typical Specification for Metallurgical Grade Fluorspar

Calcium fluoride (Effective)	75-80%	minimum
Silica	2-6%	maximum
Calcium carbonate	2-3%	maximum
Sulphur	0.01-1.0%	maximum
Lead	0.02-0.25%	maximum

*References Collings and Andrews 1988b; Law, Sigurdson and Associates SRI International 1989.

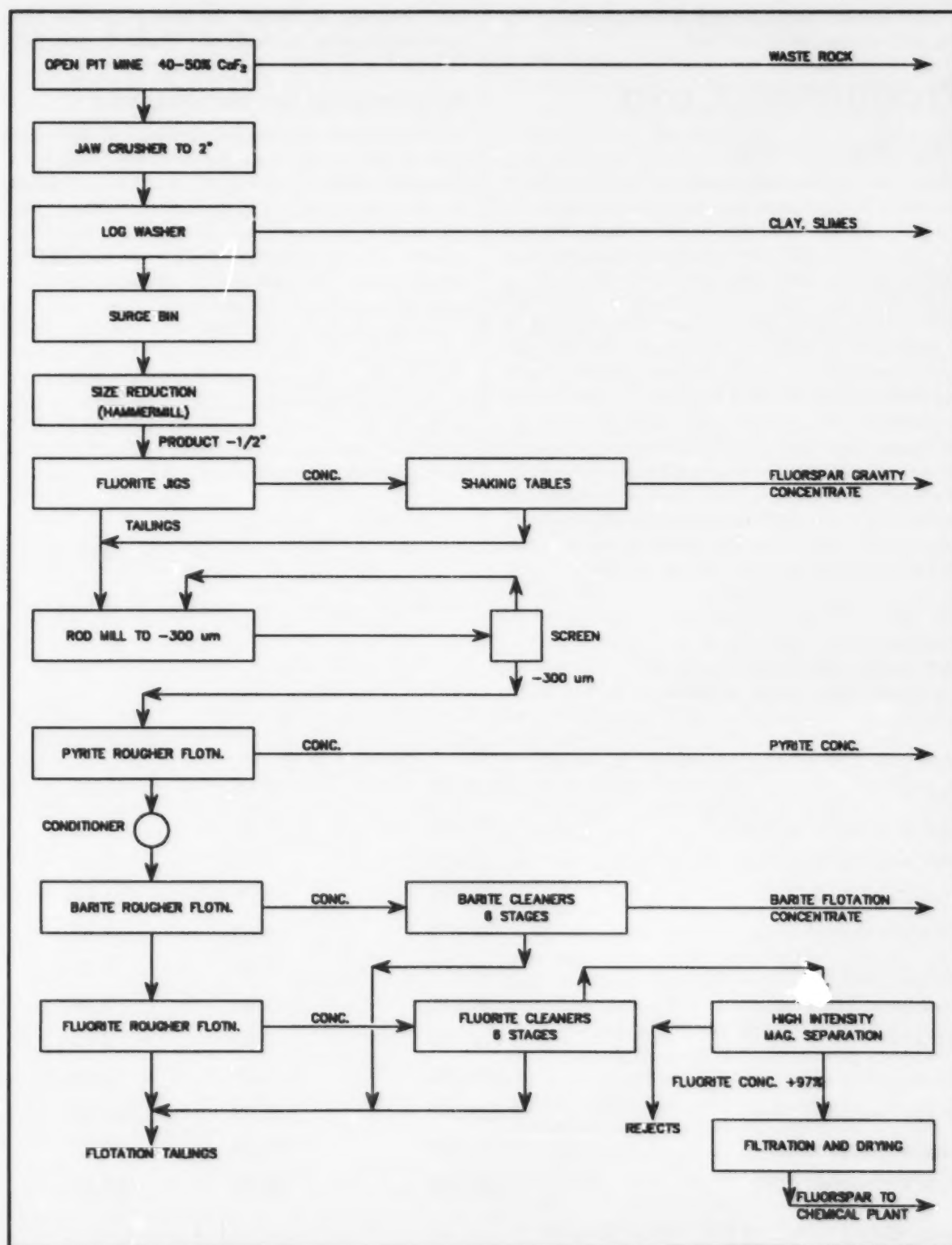


Figure 10. Fluorspar Recovery from Vein Mine.

Size analysis specifications appear to restrict the quantity of fine and coarse fractions.

Production Costs

Acid Grade Material

A proposed fluorspar processing plant would be located centrally to treat ores mined from a number of vein deposits in the Madoc area. The production rate considered is 15,000 tonnes per year of fluorspar concentrate meeting acid grade specifications.

The estimated capital cost of the facility is approximately \$3.8 million. Mining costs for development of deposits are not included and it is assumed that mining on a contract basis, or by owner-operators of small deposits, will supply feed to the plant. Preliminary information on the sizes of major items of equipment and typical purchase costs are provided in Appendix C. A total of 14 personnel are required for plant operation and administration, plus contractors engaged in mining and trucking. The estimated production cost is presented in Table 44. The direct operating cost, including mining and ore haulage, is approximately

\$147 per tonne of product. The total production cost including repayment of capital (within five years) is estimated to be \$198 per tonne of product.

Metallurgical Grade Material

The production of metallurgical grade fluorspar from the known Ontario deposits has not been considered in detail due to the small volume and dispersed nature of the deposits, and the limited market potential. Metallurgical grade material could be produced by a simple gravity processing plant or as a secondary product from a plant designed to produce acid grade material as a primary concentrate.

A very preliminary estimate of capital cost is approximately \$2 million for a plant designed to treat the proposed mine output of 46,000 tonnes per year, using gravity recovery only. The direct operating cost would be in the order of \$70 per tonne of product (70% CaF₂) and the total production cost, including capital repayment, approximately \$90 per tonne.

Table 44
Mill Production Cost Summary
Fluorspar Mill Open Pit Mine

	ANNUAL COST, \$	UNIT COST, \$/t ore	UNIT COST, \$/t Product
Payroll	582,000	12.65	38.80
Reagents and Supplies	391,000	8.50	26.07
Maintenance Supplies	30,000	0.65	2.00
Power and Fuel	171,000	3.72	11.40
Contract Mining	644,000	14.00	42.93
Ore Haulage to Mill	18,400	0.40	1.23
Insurance, taxes etc	50,000	1.09	3.33
General	122,000	2.65	8.13
Contingency	200,840	4.37	13.39
Direct Operating Cost	2,209,240	48.03	147.28
Capital Repayment	760,700	16.54	50.71
Total Production Cost	2,969,940	64.56	198.00

Note: Milling Rate = 46,000 tonnes per year
Product Rate = 15,000 tonnes per year

6. Implications for Small Mines

Custom Milling

The deposits of barite and fluorspar occurring in Ontario are generally small, often narrow vein deposits. The proposed production options for the major deposits are designed on the basis of centrally located processing plants in order to optimize costs and handling of material. The proposed location of the plants would also allow smaller quantities of ore, supplied by independent operators in the immediate area, to be treated on a custom milling basis.

Barite

A barite processing plant located in the Thunder Bay area could provide a valuable custom milling opportunity. The plant as proposed would be designed to receive ore from several vein deposits in order to satisfy either of the indicated production rates of 15,000 tonnes per year or 30,000 tonnes per year. Since ore from the major deposits will be trucked to the crushing station at the plant, other suppliers could quite feasibly use the same approach. A number of small vein deposits are known to occur within the district and most of them are probably within economic haulage distance of a suitable mill site.

The known deposits generally contain a high proportion of barite and contaminants seem to be fairly constant thus predictable. It is possible that other small deposits worked by independents or owner-operators could supply small portions of the feed to such a mill.

Supplies of custom ore could be stockpiled at the mill site to allow a campaign type operation or could be blended with the regular mine production if similar in grade. The campaign method is probably better suited to this project where the milling operation is not continuous and payment for custom ore may depend on recovered mineral quantities.

For the North-Eastern region of the province the same possibilities exist for custom ore milling except that the distances between some of the noted deposits tend to be greater. The viability of a processing facility in this area will in part depend on the availability of ore supply from the existing mining operations. Ore from other known deposits appears to be compatible with the present ore supply and this does present an opportunity to develop small deposits if they are found within an economic haulage radius. The proposed plant for this area is also designed for two shifts per day of operation, five days per week, so it could easily accommodate a fluctuating supply of additional ore, and allow process changes between campaigns.

The South-Eastern region could probably benefit from the services of a custom milling operation; it is assumed that some of the available small reserves could be mined by local owners for treatment at a nearby plant. However, justification for such an installation requires considerably more work and data collection to develop a regional reserve estimate.

Fluorspar

The major occurrences of fluorspar are stated to be in South-Eastern Ontario in the vicinity of Madoc, and the proposed fluorspar processing plant is suggested for this area. This plant would depend on supply of ore from a number of separate vein deposits, probably even at the relatively low production rate of 15,000 tonnes per year. While ownership of the deposits has not been researched, it is likely that some of these fall into the category of independent owner/operators. As such, the proposed plant is, in part, a custom mill.

The establishment of a plant in the area, designed to treat a variety of deposits, will encourage exploration and development of other deposits by local owners who could not afford to participate in the initial enterprise. As with the barite plant, the design allows for easy expansion of production and campaigning of separate ore supplies. The processes included also allow rejection and/or recovery of other minerals.

By-product Recovery

Barite at Hemlo

The three producing gold mines at Hemlo are mining ore from underground workings using modern, cost effective techniques. These operations are profitable due to the gold content of the ore and the large tonnage, efficient operations. In effect, the barite available in the tailings of the Hemlo mills is mined at zero cost. Unless there are easily worked, high grade surface deposits of barite in the area, it is doubtful a new or independent operation could produce barite at a similar or lower cost than projected for the proposed tailings treatment plant.

It is possible that other gold (or base metal) deposits will be developed in the area, and possibly as small operations. Ore from such potential operations may contain barite, but it is unlikely that the barite content would be considered in establishing the feasibility of a new operation.

The operating gold mills are presently running at capacity and there is a low probability that the option of custom milling ore from other sources would be entertained.

Fluorspar

Within Ontario there is no known current mining operation where an ore is being processed which also contains significant quantities of fluorspar. However, there are mining and milling operations in areas where fluorspar ore could be mined on a small scale (North-Western and South-Eastern Ontario).

While these existing mills do not have fluorspar recovery circuits installed, it is quite probable that a minor amount of additional equipment could be installed to allow co-processing of a fluorspar supply. Such a facility would allow crushing and grinding of the custom ore in parallel operation or on a campaign basis. The use of either excess flotation capacity or additional flotation equipment for fluorspar processing would then incur a fairly low level of new capital expenditure.

The advantage to potential custom shippers would be the available infrastructure, shared labour costs and services of an existing plant.

Barite/Fluorspar Joint Recovery

The noted vein deposits of the Madoc area and some occurrences in the Thunder Bay area contain both barite and fluorspar. For the Madoc deposits mined in the past, selective mining and/or hand sorting was practised in order to separate the two minerals to a

maximum extent prior to processing. Guillet (1963) reported that concentrates of both barite and fluorspar were produced at the Noyes Mine.

The fluorspar processing plant proposed earlier in this report includes processes to remove barite prior to recovery of fluorspar. This would be a necessity for a plant in the Madoc area in order to meet acid grade fluorspar specifications.

With recent advances in the development of flotation chemicals, it is conceivable that such a plant could process a variety of ores to produce acceptable barite and fluorspar concentrates. This would be advantageous to operators of small mines where selective mining is not effective or economic.

Plant operation would probably be controlled to either process a fixed blend of ores or to combine ores of widely different barite/fluorspar ratios. This would suit small mine production where production rates might fluctuate on a short term.

7. Conclusions and Recommendations

Conclusions

1. Development of a plant to produce 30,000 tonnes per year of chemical grade barite appears practical for several areas in the province, based on preliminary information concerning resource volumes and grade. The most attractive possibility is a facility located near Thunder Bay, producing barite at an estimated cost of \$108 per tonne.

2. Similar production rates for barite might be achieved by mills at Hemlo or near Matachewan but production costs will be higher. Current operations at these locations may also restrict development or impose added costs.

3. The production of BaS , BaCO_3 and possibly BaSO_4 in a multi-product carbonate/sulphate plant appears to offer reasonable technical and economic potential provided that low cost barite can be delivered to the barium chemicals plant and that the reported market prices for these chemicals are realistic for large volume quantities. Production rates and plant gate production costs for these chemicals, using \$108 per tonne barite are shown in Table 45.

4. The production of BaCl_2 , BaO and Ba(OH)_2 does not appear to have any significant economic potential as indicated production costs are well in excess of reported market prices in Canada and the Eastern United States even with low price barite.

5. Product transportation costs are significant and siting of the barium chemicals plant relative to the barite milling operation(s), existing transportation systems and the barium chemicals marketplace is an important consideration.

6. The most likely area for development of a fluorspar processing facility appears to be in the region near Madoc. Acid grade fluorspar could be produced but the operation may be limited by the available mineral resource. A cost developed for production of 15,000 tonnes per year of acid grade material is \$198 per tonne.

7. The most attractive processing options for both barite and fluorspar favour custom milling opportunities for small mine operators. The fluorspar plant would also allow co-processing of barite-rich ore for the possible production of two concentrates.

8. The costs developed for this study must be considered as preliminary. They are based on a minimum level of information concerning mineral deposits, metallurgical testing and processing options. The documents referenced have been relied upon implicitly for all raw data.

Table 45

Production Rates and Plant Gate Costs for Barium Sulphide, Barium Carbonate and Barium Sulphate

	Production Rate, t/a	Production Cost, \$/t
Barium Sulphide		
- captive use	15,600	
- net sales	4,400	413
Barium Carbonate	12,000	592
Barium Sulphate	1,000	815

Recommendations

1. It is recommended that additional work be conducted to establish the validity of the most attractive options for barite and fluorspar production. The most critical is the need to establish a base level of proven and probable reserves of the economic minerals.

2. Following investigation of reserves, studies must be conducted to:

- Test representative samples of the reserves to develop efficient and cost effective metallurgical processing routes;
- Examine potential mine and plant locations in order to define costs of land acquisition, site development, buildings, tailings disposal, infrastructure and supply of services;
- Complete a market survey for the minerals being considered;
- Conduct feasibility studies for the selected minerals and processing options.

3. Following successful completion of a feasibility study to define the processing costs for high quality barite (94% BaSO₄ minimum), chemicals production studies must be conducted to:

- Better define the market opportunities for primary barium chemicals (sulphide, carbonate and sulphate) in Canada and the Eastern United States in terms of probable volumes that can be marketed and competitive prices that can be realized.
- Examine potential chemical plant locations in order to minimize barite ore, raw materials and final product transportation costs.
- Examine the potential market for by-product sodium sulphide.

- Conduct a detailed feasibility study on production of the selected barium chemicals at production rates determined by the results of the market analysis and the barite mineral availability/cost studies.

Only after these studies and investigations have been completed can serious consideration be given to proceeding with the development of barite and fluorspar reserves in Ontario and to the consideration of barium chemicals production to take advantage of potential market opportunities in Canada and the Eastern United States.

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Appendix A
Barite Mill Processing Equipment
Major Items and Typical Costs (not installed)

1. Barite Mill, 30,000 tonnes per year Thunder Bay-Matachewan

EQUIPMENT NAME	SIZE	TYPICAL COST \$
Jaw Crusher	24" x 36"	100,000
Hammer Mill	10" x 20"	50,000
Jig Duplex	24" x 36"	20,000
Shaking Table	Full Size	16,000
Rod Mill, 100 HP	5' Dia. x 10'	* 70,000
Flotation Cells	6 @ 1.4 m	360,000
Vacuum Filter c/w Pumps	6' Dia. x 4 Disc	* 50,000
Rotary Dryer c/w Fuel System	6' Dia. x 36'	*250,000
Building	12 m x 24 m	60,000

*Denotes used equipment price.

Appendix A
Barite Mill Processing Equipment
Major Items and Typical Costs (not installed)

2. Barite Mill, 30,000 tonnes per year, Hemlo Gold Mill Tailings

EQUIPMENT NAME	SIZE	TYPICAL COST \$
Flotation Cells (Pyrite)	6 @ 5 m	3150,000
Flotation Cells (Molybdenum)	6 @ 5 m 18 @ 1.4 m3	3150,000 270,000
Flotation Cells (Barite)	6 @ 3 m 18 @ 0.7 m3	3120,000 126,000
Vacuum Filter c/w Pumps	6' Dia. x 4 Disc	* 50,000
Rotary Dryer c/w Fuel System	6' Dia. x 36'	* 250,000
Building	18 m x 43 m	170,000

*Denotes used equipment price.

Appendix B
Barium Chemicals Plant Equipment
Major Items and Typical Costs (not installed)

1. Barium Sulphide Plant

EQUIPMENT NAME	SIZE/CAPACITY	TYPICAL COST \$
Barite Mill	5.0 t/h, -1/2" to - 20 mesh	100,000
Rotary Kiln c/w Fuel System 1,250°C, & Pollution Control	6' Dia. x 60', Refractory Lined	1,400,000
Sulphide Grinder	3.2 t/h, Clinker to -20 mesh	40,000
Barite Silos (2)	12' Dia. x 32'	40,000 ea
Coal Silo	12' Dia. x 32'	40,000
Barite Feeder	4.0 t/h	40,000
Coal Feeder	0.5 t/h	20,000
BaS Solution Tanks (4) c/w Agitators	8' Dia. x 14', SS	36,000 ea
Decant Tank	10' Dia. x 9', SS	24,000
BaS Storage Tanks (2) c/w Agitators	12' Dia. x 20', SS	40,000 ea
BaS Sludge Tank c/w Agitator	8' Dia. x 14', SS	36,000
BaS Screen	3' Dia. Single Deck	8,000

Appendix B
Barium Chemicals Plant Equipment
Major Items and Typical Costs (not installed)

2. Barium Carbonate (+ Sulphate) Plant

EQUIPMENT NAME	SIZE/CAPACITY	TYPICAL COST \$
BaCO ₃ Reaction Tank c/w Agitator	8' Dia. x 14', SS	36,000
Vacuum Filters (2) c/w Pumps	6' Dia. x 6', SS	60,000 ea
BaCO ₃ Paddle Dryer	450 sq ft heat transfer area, SS	320,000
BaCO ₃ Grinder	2.5 t/h, -1/16" to -10um	32,000
Na ₂ S Evap/Crystallizer	10,000 kg/h evap, SS	400,000
Na ₂ S Centrifuge	4 m ³ /h feed, 30% solids, SS	100,000
Na ₂ S Paddle Dryer	90 sq ft area, SS	120,000
Na ₂ CO ₃ Silos (2)	12' Dia. x 32'	40,000 ea
Na ₂ CO ₃ Solution Tank c/w Agitator	8' Dia. x 8', SS	24,000
BaS Solution Tank c/w Agitator	12' Dia. x 14', SS	36,000
BaCO ₃ Screen	3' Dia. Single Deck	8,000
Na ₂ S Screen	2'6" Dia. Single Deck	6,000
BaCO ₃ Silos (2)	12' Dia. x 24'	35,000 ea
Na ₂ S Silos (2)	12' Dia. x 32'	40,000 ea
Na ₂ SO ₄ Solution Tank	8' Dia. x 8', SS	24,000
BaSO ₄ Silo	8' Dia. x 14'	20,000

Appendix B
Barium Chemicals Plant Equipment
Major Items and Typical Costs (not installed)

3. Barium Chloride Plant

EQUIPMENT NAME	SIZE/CAPACITY	TYPICAL COST \$
BaCl ₂ Reaction Tank c/w Agitator	6' Dia. x 6', Lined	40,000
BaCl ₂ Solution Filters (2)	10 USgpm cont. Alloy 20	15,000 ea
BaCl ₂ Evap/Cryst	1,200 kg/h evap, Host alloy/Titanium	270,000
BaCl ₂ Vacuum Filter	3' Dia. x 4', Alloy 20	30,000
BaCl ₂ Paddle Dryer	90 sq ft area, Alloy 20	150,000
Na ₂ S Reaction Tank	6' Dia. x 6', SS	15,000
HCl Storage Tanks (2)	12' Dia. x 16', Lined	38,000 ea
NaOH Storage Tank	14' Dia. x 18'	45,000
BaCl ₂ Screen	2' Dia. Single Deck	5,000
BaCl ₂ Silo	10' Dia x 20'	30,000

Appendix B
Barium Chemicals Plant Equipment
Major Items and Typical Costs (not installed)

4. Barium Oxide/Hydroxide Plant

EQUIPMENT NAME	SIZE/CAPACITY	TYPICAL COST \$
BaCO ₃ Feeder	0.5 t/h	20,000
BaO Fluid Bed Reactor c/w Fuel System, Cyclone	5' Dia. x 20', SS	300,000
BaO Paddle Cooler	65 sq ft area, SS	100,000
BaO Grinder	0.4 t/h, -1/8" to -10um	20,000
BaO Feeder	0.3 t/h	18,000
Ba(OH) ₂ Reaction	35 ft ³ /h Mixer, VesselSS	120,000
Ba(OH) ₂ Drum Cooler & Flaker	0.5 t/h	40,000
Ba(OH) ₂ Dryer	4' Dia. x 20', SS	80,000
Ba(OH) ₂ Screen	2' Dia. Single Deck	5,000
BaO Silo	8' Dia. x 18'	24,000
Ba(OH) ₂ Silos (2)	10' Dia. x 20'	30,000 ea

Appendix C
Fluorspar Mill Processing Equipment
Major Items and Typical Costs (not installed)

EQUIPMENT NAME	SIZE	TYPICAL COST \$
Jaw Crusher	24" x 36"	100,000
Hammer Mill	10" x 20"	50,000
Jig Duplex	24" x 36"	20,000
Slaking Table	Full Size	16,000
Rod Mill, 100 HP	5' x 10'	* 70,000
Flotation Cells	18 @ 1.4 m ³	180,000
Flotation Cells	30 @ 0.7 m ³	210,000
Vacuum Filter	6' Dia. x 4 Disc.	* 50,000
Rotary Dryer	6' Dia. x 36'	* 250,000
Building	12 m x 30 m	70,000

* Denotes used equipment price.
